INCORPORATING USERS INTO SANITATION TECHNOLOGY INNOVATION: CHALLENGES TO KNOWLEDGE COHERENCE BETWEEN DISCIPLINES

BY

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THESIS

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ABSTRACT

Although great progress has been made towards improving access to water worldwide, the same progress has not been observed in improving access to sanitation. While engineers are at the forefront of advancement in access to technologies, social and cultural barriers present unique challenges in the sustainability of sanitation interventions. It is clear that a better structure for incorporating user factors into sanitation interventions and sanitation technology design is required but how to go about this process is uncertain. Three primary methods for incorporating users into technology design have been popular in engineering sciences: user centered design, multiple criteria decision analysis, and appropriate technologies. International aid organizations have also popularized the concept of ‘participation’ in interventions but the concept is vague, open for interpretation, and has been criticized for its continued dependence on hierarchical, expert-driven technology interventions. Participatory action research offers an more distributive model for participation within research studies and, for this reason, we also consider participatory action research as a method that engineers can use for incorporating users into innovation and intervention processes. Through a comprehensive search of literature on sanitation technologies, this thesis examines how engineering literature on sanitation technologies includes users into the design process. Through a network analysis using a novel MATLAB script, which we call Synapse, to sort literature derived from the Scopus database, this project shows the connections and gaps in the sanitation literature and points to significant opportunities for future multidisciplinary work incorporating end users into processes of sanitation technology innovation.

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CHAPTER 1

PROBLEM STATEMENT

Introduction

Since 1990, 1.8 billion people worldwide have gained access to basic sanitation; however, with population growth, this represents only an 11% decline (from 2.8 billion in 1990 to 2.5 billion in 2010) in the total number of people without adequate sanitation (Roma and Jeffrey 2010; WHO 2012a). The Millennium Development Goal (MDG) to reduce by half the number of people without improved access to water was met five years ahead of schedule in 2010 and 2 billion people since 1990 have gained access to safer water. Although 780 million people worldwide do not have access to improved water sources, this represents a significant improvement over the past two decades. Such progress has not been mirrored in efforts to reduce the number of people without access to proper sanitation. Rural poor areas are most affected by inadequate sanitation conditions, with less than half of the world's rural population having access to improved sanitation (Jiménez and Pérez-Foguet 2010). As shown in Table 1.1, a reduction in the number of those without access to improved sanitation by half is not expected to occur until at least 2022 worldwide and 2076 in Sub-Saharan Africa. Since 1990, access to improved sanitation in Sub-Saharan African has improved however a full 51% of the population still remains with unimproved access or practices open defecation (25%; WHO 2012a).

It is estimated that 10% of global morbidity is the result of waterborne pathogens, which includes both helminths as well as pathogens that cause diarrheal disease (Elliott 2011). According to the WHO (2012a), "one gram of faeces may contain 10 million viruses, [at least] one million bacteria,[1] 1,000 parasite cysts and 100 worm eggs." Every year 1.8 million people die from diarrheal disease, 1.5 million under the age of five. An estimated 6,000 children die daily from waterborne diseases (Smith and Martin 2005). Waterborne disease as a result of contaminated water and improper sanitation results in the death of 115 people every hour in Africa (WHO 2012b). Waterborne diseases continue to be a pressing issue in many parts of the world, as unsafe water is the fourth leading risk factor for mortality and the second leading risk factor for disability adjusted life years (DALYs)[2] in low income countries (WHO 2009). Diseases that killed millions in the 19th century in Europe and the United States are still present in developing nations. Of the 140,000 cases and 5,000 deaths from cholera that were reported in 2000, 87% occurred in Africa (WHO 2012c). Through the provision of safe drinking water, proper hygiene, and safe disposal of excreta, diseases like cholera are entirely preventable.

Outcomes of the failure to address the water and sanitation needs of the poor in developing nations will be compounded by the impacts of climate change. Researchers predict that by 2030 climate change will bring about a 10% increase in the incidence of diarrheal disease (Shuman 2010). Climate change is anticipated to result in increased flooding and drought around the world (Oki and Kanae 2006). While drought will concentrate limited water bodies and create opportunities for transmisson of certain diseases, heavy rains and flooding will overwhelm sanitation systems resulting in drinking water contamination. The greatest impact of these changes will be in Africa with an estimated 3,071.5 DALYs per million people by 2030 (Shuman 2010).

The Millennium Development Goals have helped to reduce poverty but at times the enacted policies have effects that work against the intended consequences (Fukuda-Parr et al.

[1] Studies have shown that one gram of feces may contain more than one to ten billion bacterial cells (Franks et al. 1998; Gossling and Slack 1974).

[2] DALYs are years of life lost due to disability or premature death.

2013). For instance, although pit latrines have been increasingly used to meet MDGs, many pit latrines have been found to contaminate local groundwater; their environmental effects have also not been adequately explored (Graham and Polizzotto 2013). Lack of treatment of wastewater is common throughout the world such that at least 50% of the world's freshwater sources are contaminated with sewage (Baum et al. 2013). To achieve MDGs for improved water and sanitation service delivery requires significant innovation, particularly in peri-urban areas (Mara 2006), but improving access to sanitation poses related yet distinct challenges from those encountered in attempting to increase access to improved water.

Improving sanitation in urban settings involves the development of infrastructure, maintenance of the infrastructure, political and financial capacity for the management of wastewater collection and treatment systems, and social acceptance of fee payment for waste collection (Starkl et al. 2013; Guest et al. 2009). In the rural context, sanitation technology tends to be decentralized and often is at the household scale. Improving sanitation technology in the rural context requires adequate technology given the environmental constraints, low costs, education for maintenance, and social acceptance of both targeted sanitary practices as well as the technologies (Starkl et al. 2013).

As interventions are predominately expert and outsider driven, conflict can arise between target users and experts. A top down structure cannot adequately address local context, which typically leads to infrastructure failure and abandonment (Starkl et al. 2013). Starkl et al. (2013) found that 55% of systems that appeared to be successes in fact were hidden failures. Hidden system failures include those that that appear to be successes but that either ultimately do not sustain long term adoption or do not deliver the intended quality of product due to malfunction, poor design, lack of proper maintenance or operation. Problems that may impede successful implementation of sanitation interventions include user rejection of the technology, lack of user awareness for the need of water treatment or sanitation, rejection of necessary behavioral changes, and failure to see value in and carry out regular maintenance (Black 1999; Blume and Winker 2011; Starkl et al. 2013). In assessing intervention success, communication breakdowns may occur when target recipients experience a power differential and feel compelled to tell perceived experts what they believe the experts want to hear rather than what the users actually desire or are willing to do (Mosse 2001). Without proper, consistent, and widespread adoption of water and sanitation interventions, intended health gains from interventions will not be seen (Brown and Clasen 2012).

Given the significant impact that impaired sanitation has on quality of life and life expectancy for poor populations, understanding how to improve basic sanitation conditions throughout the world is imperative. Unfortunately, because impaired sanitation has a complicated relationship with poverty and social inequalities, clear pathways for improving sanitation access are not available. Instead, those interested in contributing to sanitation interventions in developing countries must reflect on how best to engage with target users and what their role is in developing and executing said interventions. Because many sanitation interventions fail because of lack of user acceptance, the focus of this thesis is on how sanitation interventions have considered user participation in the intervention process. In order to understand the role that technology plays in intervention success, this thesis specifically focuses on the ways in which engineers incorporate target users into technology and intervention design.

Overview of Chapters

After this introduction, Chapter 2 provides background literature on sanitation intervention efforts and the dominant themes in how interventions have attempted to address user acceptance of sanitation technologies. Beginning with a historical review of international priorities related to sanitation improvement, the chapter establishes how certain approaches to user acceptance have emerged. Three dominant themes are identified as efforts to increase technology and intervention fit in developing countries. These themes include the appropriate technologies movement, the shift from ‘hardware’ to ‘software,’ and finally, the increasing emphasis on user participation in intervention planning. To contextualize these efforts within the global push towards sustainable sanitation, the chapter examines how these approaches have been used in resource recovery schemes for improved sanitation. The chapter concludes with a discussion of how poverty complicates efforts to address impaired sanitation in the developing world and how intervention efforts may inadvertently exacerbate structural contexts that lead to the impaired living conditions that interventionists hope to address.

To better understand how engineers, specifically, attempt to incorporate user considerations into sanitation technology design, Chapter 3 elaborates on a method for processing the breadth of literature on sanitation and user acceptance across disciplines. By targeting the literature on the developing world that includes mention of engineers, we hope to describe how engineers make use of interdisciplinary perspectives to transform conventional engineering approaches to sanitation technology innovation. To meet this challenge, we have developed a novel software application, Synapse, to process citation data for bibliometric analyses making use of the Pajek (Batagelj and Mrvar 2008) network analysis software. An introduction to Synapse is provided in Chapter 4 along with an overview of the current progress in its development, its limitations, and next steps for continued development. Chapter 5 discusses the conclusions of this study, including its significance and utility to engineers.

CHAPTER 2

BACKGROUND AND MOTIVATION

Sanitation as an International Priority

Global health initiatives to improve environmental sanitation conditions date back at least to 1948 when the World Health Organization established improving environmental hygiene as one of its core functions through the formation of the Expert Committee on Environmental Sanitation (WHO 2003). The first outcome from the committee was a report published in 1949 which stated that wellbeing is impacted by environmental factors including having safe drinking water and sanitation. During the 1950s the WHO worked to establish demonstration projects to show that health in developing countries could be improved through proper water treatment and hygienic sanitation facilities. In 1961 the Charter of Punta del Este set the first international targets for water supply and sanitation and 1977 the United Nations Water Conference was held in Mar del Plata, Argentina where it was proposed that the 1980s should be established as the International Drinking Water Supply and Sanitation Decade (the Decade; Black 1999, Jiménez and Pérez-Foguet 2010).

In 1980 the United Nations General Assembly (UNGA) declared the 1980s as the International Drinking Water Supply and Sanitation Decade wherein the goal the during this time was to provide access to water and sanitation for 100% of the world's population (Jiménez and Pérez-Foguet 2010). During this period there were many conflicts in water and sanitation interventions where interventions were unwanted and target populations were unwilling to pay for water and sanitation services (Eawag 2005). Although the target of 100% coverage was not met, significant improvements in water and sanitation delivery were achieved (WHO 2003). At the end of the Decade the Water Supply and Sanitation Collaborative Council (WSSCC) was established to continue the momentum of water and sanitation improvements that occurred over the previous ten years (WHO 2003).

During this same timeframe, significant events occurred that transitioned development projects away from conventional planning to sustainable development planning. In 1983 the United Nations commissioned Gro Harlem Brundtland, the Prime Minister of Norway, to conduct an inquiry into the question of global environmental problems and their relationship to development. The outcome of the Brundtland Commission was a report entitled *Our Common Future*, which was published in 1987. The Brundtland report introduced the language of sustainable development to the mainstream and political audiences. Prior to the report, the concept of sustainable development was used outside of global development organizations as part of environmental and justice discourse, which examined ways to find inexpensive and culturally appropriate solutions to address issues of poverty in developing countries. Brundtland drew from these ideas to argue for the possibility of development without sacrifice. The report stated that issues of environmental degradation did need to be addressed, but that the "economic growth, environmental improvement, population stabilization, peace and global equity" could all be pursued concurrently without sacrificing one for the sake of the other (Dryzek 1997, p148). The Brundltand Report stimulated discussion about environmental sustainability of human actions and introduced the concept of sustainable development, which was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their [own] needs" (Black 1999, p28).

The first Earth Summit, officially recognized as the United Nations Conference on Environment and Development (UNCED), was held in Rio de Janeiro in 1992 (Lammerick 1998). The Earth Summit affirmed international commitment to achieving universal access to clean water and hygienic sanitation facilities. Officially, the summit endorsed Agenda 21, which argued that global environmental problems are the result of production and consumption in the richer countries in the world. At the same time, Agenda 21 did not call for a reduction in production or consumption but instead recommended further economic development as the solution (Dryzek 1997). Agenda 21 was criticized for speaking vaguely about information, coordination, and management, but it lacked concrete recommendations for reduction of accumulation (Sachs 1993).

The Bellagio Principles, established in Bellagio, Italy in 1996, put forward a set of criteria for evaluating progress towards sustainable development. These criteria included ensuring long-term planning goals; assessing whether development impacts were overall beneficial and addressing basic human needs; whether projects were transparent and engaged broad participation of those impacted by the development projects; and whether continuing monitoring and assessment was used to make ongoing improvements (Hardl and Zdan 1997). The Bellagio Principles for Sustainable Sanitation, announced in 2000 declared that sanitation interventions should provide for basic human dignity, involve all levels of stakeholders including target users, allow for resource recovery from water and water streams, and minimize the distribution of wastes outside of their place of origination (Lüthi et al. 2007). Although WHO development projects had early recognized the importance of incorporating users into development projects, the Bellagio Principles and the Bellagio Principles for Sustainable Sanitation firmly established participation as core priorities in sanitation development initiatives. A key contribution of the Bellagio Principles for Sustainable Sanitation was the attention to developing projects that allow for resource recovery from wastewater.

In 2000 the UNGA gathered in New York to announce the Millennium Development Goals, which set specific targets for improved human development through eliminating poverty and hunger, achieving universal education, promoting gender equality, reducing child mortality, improving maternal health, combating disease, ensuring environmental sustainability and increasing global partnerships. Under the category of ensuring environmental sustainability, the original MDGs in 2000 established the aim to reduce by half the percent of the world's population without access to clean water by 2015 (UNGA 2000). In 2002 at the World Summit for Sustainable Development in Johannesburg a clause was added to the Millennium Development Goals to halve the rate of those without improved sanitation by 2015 (Walgate 2002; WHO 2003). The year 2008 was dubbed the International Year of Sanitation to bring attention to the large share of the world's population that lacks access to basic sanitary facilities and hygienic resources (Jiménez and Pérez-Foguet 2010). The Post-2015 development goals focus on ending open defecation by 2025, increasing handwashing, and providing adequate sanitation in the home.

Approaches to Sanitation Intervention

In spite of long-standing international emphasis on incorporating users and prioritizing the sustainability of sanitation interventions, the actual implementation of projects has lacked both. In September of 2012 the European Court of Auditors released a report that detailed their examination of 23 projects aimed at improving water, sanitation, and hygiene access in six countries in Sub-Saharan Africa (ECA 2012). The Court expressed concern for the incongruity between the aims of these projects and their realized outcomes. The Court felt that the projects were carried out with operational technologies that are capable of improving water and sanitation conditions but that the projects themselves largely failed to account for adequate financial mechanisms to cover the long term costs of operation and maintenance, tariff structures that were consistent with the target communities' beliefs regarding the fair costs of water and sanitation, and the need to develop buy-in and sense of ownership amongst community members. While the projects intended to improve health outcomes, improvements were marginal and difficult to measure.

While there exists a collective understanding that user inclusion is necessary for successful implementation of development projects, what user inclusion actually entails and how it is carried out varies substantially. International development projects have seen at least three major frames emerge related to addressing user acceptability of development projects. These frames include the appropriate technologies movement which was popular from 1978 to 1988, a shifting emphasis from 'hardware' to 'software' between 1988 and 1994, and an intensified 'participation' thrust which was at it peak between 1994 to 1998 (Black 1999). Although these frames each experienced periods of widespread support, in actuality none has completely been abandoned and many interventions involve differing emphasis on each frame.

Appropriate Technologies

Appropriate technology comes from Ghandhism and the effort to improve access to desirable technologies for underserved populations. The concept was made well known through E.F. Schumacher's book *Small is Beautiful* (1973). Appropriate technologies was a response to the convention of direct technology transfer which placed externally developed technologies within entirely different cultural contexts (Nieusma and Riley 2010). These technologies inevitably failed because they were not specifically targeted at being affordable nor were they able to be maintained with readily available, low-cost, sustainable materials.

One challenge with the appropriate technologies framework is that it does not advocate a specific approach, so what "appropriate" means, how that definition is created and by whom is entirely open (Willoughby 1990). In some cases "appropriate" was defined entirely based upon cost constraints, limiting other choices that may have had more cultural relevance or have been safer in preference for the least expensive option. Appropriate technologies need not necessarily be the least expensive option but rather must be appropriately priced at the level residents are willing to pay for the product or service (Murphy et al. 2009). One definition of appropriate technologies is that they are technologies that meet a basic unmet need of residents, function properly, and achieve a satisfactory level of compliance (Murphy et al. 2009). An inappropriate technology is one that does not achieve its intended treatment goal even though it may be satisfactory to residents (Murphy et al. 2009).

One example of an appropriate technologies project was the UNDP Handpumps Project. In 1981 the UNDP funded a project for the Technological Development of Community Water Supply Handpumps (Black 1999). The Handpumps Project was created to transfer lab tested water technology at a large scale to low income, developing world populations. For this project, five years of lab testing for efficacy preceded field-testing. Pumps were designed to keep costs low and initial acceptability appeared to be high. The hand pumps required maintenance, however, which was carried out through centralized, trained operators. This method of handling maintenance was inefficient, expensive due to travel costs, and maintenance activities were not timely. As a result of poor maintenance, many pumps were abandoned for poorer quality but reliable water sources. The Handpumps Project was concluded in 1991, having had mixed success.

Appropriate technologies as a frame, by emphasizing social justice over technology delivery, places attention on relationships of power between engineers, NGOs and community members; economic constraints within a larger economic structure; and the sustainability of projects for community members over the lifespan of the intended intervention (Nieusma and Riley 2010). It challenges the mindset regarding whom the system belongs to and for whose benefit. In practice, though, appropriate technologies often still draws from a top down organization where experts teach residents of developing countries about Western science ideals within what are determined externally to be appropriate technologies. In this way appropriate technologies often relies on knowledge transfer from developed to developing countries (Murphy et al. 2009).

The appropriate technologies movement was criticized because it implied that developing countries were not capable of or were unworthy of the design standards required in more developed countries (Brooks 1981). It was also criticized for implying the complete rejection of the current mass-marketable technology structure in favor of a highly localized, niche technology system. Of greater concern, though, was the appropriate technology movement's by in large failure to bring about radical transformation in social conditions through increasing technology choice for developing country settings (Willoughby 1990). Nonetheless, the appropriate technologies movement did bring attention to the importance of context for introducing technology advances in low-income settings (Nieusma and Riley 2010). The appropriate technologies movement helped to bring about the understanding that 'hardware,' as in low-cost technology, was only part of the problem while 'software,' understanding of need and the knowledge to use and maintain the hardware, was also a significant factor in project success (Black 1999).

Hardware to Software

Beginning in the mid-1980s the emphasis in development projects shifted from technologies (hardware) to addressing intangible issues (software; Yacoob and Whiteford 1994). The emphasis on software asserts the importance of individual behaviors, gender equity and the inclusion of women, general community participation, cost recovery structures, and community capacity building (Black 1999). Often, though, addressing software has meant stimulating behavioral change through education campaigns. Because changing behavior is typically inherent to the use of new technologies and because the elimination of certain behaviors (e.g., open defecation) is preferred, changing behaviors is key to improving living conditions and advancing sustainable development. Behavioral change campaigns have been met with mixed success and many failures (Arnold et al. 2009).

There are a variety of ways in which interventions can try to influence behavior. These techniques coalesce around six different approaches including 1) providing education about the problem and/or instructions on how to modify behavior to address the problem, 2) using demonstrations to model how to change behavior, 3) helping participants to solve problems related the target problem, 4) identifying or mobilizing peer support groups to encourage behavior change, 5) providing products to facilitate change, and 6) using different forms of media such as pictures, songs, or posters to distribute information about the need for behavioral change (Briscoe and Aboud 2012). The most successful behavioral change interventions adopt multiple approaches to engage with and stimulate participants in a variety of ways.

The "Theory of Planned Behavior" states that practices will be determined by individuals' feeling about the practice, the influence of social norms on the practice, and whether individuals feel as though they have control over the practice (Ajzen 1991; Lienert and Larsen 2006). Lienert and Larson (2006) say that changes in practices will occur based upon whether individuals feel as though the behavior change can be accomplished after factoring in the barriers to changing the practice (e.g., convenience, degree of displeasure arising from the changed practice, cost, materials, transportation, etc.), knowledge about how to go about changing the practice, and motivation to achieve the perceived gains from new practice.

Behavioral change programs are commonplace today. Hand-washing behavioral change interventions have struggled to realize ideal success rates, with some studies showing adoption at less than 50% (Aboud and Singla 2012). Similarly, other studies of water treatment adoption have shown that only 27% of twenty-six point-of-use water treatment interventions saw long-term adoption among at least 50% of households (Fiebelkorn 2012). Other studies have demonstrated successes. Six years after interventions to improve water knowledge and practices, researchers found two-thirds of people were continuing to use the health promoting behaviors learned during the original intervention (Eder et al. 2012). A study of household water treatment found that when people were compliant with a treatment protocol, incidence of childhood diarrhea decreased but lack of compliance led to no observable health gains (Enger 2013). The researchers in this case concluded that better guidelines for measuring and promoting compliance would help for adherence to household water treatment and subsequent wide-scale reduction in childhood diarrhea.

One campaign that has been considered a success is the *Choo-Bora* campaign in Tanzania (Perez et al. 2012). *Choo Bora* Sanitation is a campaign led by the Water and Sanitation Program's (WSP) Scaling Up Rural Sanitation Team, which is a program of the World Bank. *Choo Bora* appeals to notions of modernity by associating using a toilet with being part of a modern civilized family. The *Choo Bora* Sanitation campaign in Tanzania is contrasted with the *Lik Telek* campaign in Indonesia which associated open defecation with shame, dirtiness, and backwards behavior (see Figure 2.1).

On their own, behavior change campaigns reduce complicated barriers to acceptability of interventions. With programs like *Choo Bora* and *Lik Telek*, although successful, these campaigns reasserted and entrenched the valuation of certain populations as having more appropriate and "better" ways of living. Such valuation of ways of living inadvertently reinforces social ordering and social inequalities that ultimately contribute to the kinds of poverty related outcomes that are attempting to be addressed through such interventions. Figure 2.2 outlines a number of factors, including intended use of resources, awareness, willingness to pay, religious and legal constraints, which affect the success of a wastewater reuse schemes but many of which are also relevant to successful adoption of other interventions as well.

Many behavior change campaigns emphasize education to facilitate behavior change. Lack of knowledge or understanding has been cited as one reason for failures of water and sanitation initiatives (Davis and Iyer 2005). For wastewater management projects to be successful, communities must be able to operate systems independently within their local physical, social, and economic structures and adequate training and education must occur (Fuchs and Mihelcic 2011). Lack of knowledge about wastewater treatment limits participation in wastewater management (Gen 2010). By including users into planning stages, interventions are more likely to achieve desired community benefits, provide more appropriate cost structuring, have better and longer-term adoption, and experience general community wellbeing enhancement (Roma and Jeffrey 2010).

Participation

User participation in project planning is seen as key to improving acceptance and sustainability of interventions (Roma and Jeffrey 2010). An understanding the importance of user participation in development projects dates back over fifty years to the earliest projects carried out by the WHO, but emphasis on participation gained traction with the announcement of the Bellagio Principles in 1996. Since that time, the importance of understanding users' values and perceptions related to the development and introduction of new sanitation technologies has been widely acknowledged (Lienert and Larsen 2006; Lopes et al. 2012; Murphy et al. 2009; Pahl-Wostl et al. 2003; Starkl et al. 2013).

In spite of widespread recognition that users need to be incorporated into interventions, there is neither a uniform standard of practice nor consensus on exactly what participation means for development projects (Hendriksen et al. 2012). The World Bank has defined participation as "a process through which stakeholders influence and share control over development initiatives, decisions and resources which affect them" (Black 1999, p32). Murphy et al. (2009) define participation as capacity building organized around developing the human skills and capital necessary to carry out successful development projects. They say that design processes should be iterative through a process of "collaborative innovation" (Murphy et al. 2009, p166).

Sherry Arnstein (1969) was critical of forms of participation that do not involve redistribution of power and instead serve to reinforce structures of inequality. Arnstein (1969) identified a typology of eight levels of participation ranging from non-participation (manipulation and therapy), tokenism (informing, consultation, and placation), to real citizen power (partnership, delegated power, and citizen control), where the lowest forms of participation actually serve to educate or cure participants rather than enable mutual cooperation and coproduction of knowledge.

Within Arnstein's (1969) typology, non-participation is the lowest category in the spectrum of participatory models. Within non-participation models, the lowest form of participation is *manipulation* wherein the purpose of including citizens is to educate them on why they should adopt a particular perspective. Experts educate while citizens learn that their perspective is incorrect and that they need to adopt the expert's perspective as truth. Often these types of interventions involve information gathering, which appears to be a method of including citizen perspectives but in actuality is a mechanism for gaining information to better target educational tools for changing citizen perspectives. Many behavioral change campaigns related to ending open defecation practices fall into this category. Another form of non-participation, according to Arnstein (1969) is *therapy* in which participants are treated as having flawed individual mental health or attitudes as a cause of their lack of power. Therapy looks at treating individual well-being and attitudes over addressing the structural reasons that lead to why these individuals experience poor health outcomes.

Participatory models reach conflict when projects that are developed externally 'for the good of the community' seek to include residents as participants in the process of implementation (Ashipala and Armitage 2011). Often residents see these development projects as intrusive and paternalistic so they resist engagement. Such models also often include participation only at the level of community leaders who may not speak for residents and who are immersed in local power inequalities. To better address the needs and concerns of target populations Ashipala and Armitage (2011) recommend a holistic approach that attempts to address multiple community challenges and not only those that the interventionists deem as most important. When projects have predefined limitations on the scope of the problem that they are trying to address they tend to restrict the ability of residents to shape how the intervention will take place and ultimately such limitations restrict the full participation of the target population. By adopting a holistic approach to problem solving, more opportunities for resident participation exist.

The second category of participation in Arnstein's typology of participation is tokenism. Beginning to move towards true forms of participation, Arnstein (1969) identifies *informing* as the lowest form of token participation. With *informing* citizens are taught about their options and rights within a set of pre-determined outcomes. Informing may involve highly technical language and jargon in an effort to include citizens in processes that impact their lives while not actually making that information accessible or actionable. *Consultation* is another form of token participation wherein citizen attitudes are gathered, through surveys, focus groups, public hearings, and meetings but the information gathered is treated summarily, with this being the extent of citizen contribution to process shaping. Arnstein (1969, p219) describes this as citizens having "participated in participation." *Placation* is the final form of token participation. With placation, a small number of citizens are selected in planning processes but these individuals represent certain types of citizens that are considered deserving of participation, that are generally deferent to the decisions made by experts in the group, or that express needs that are consistent with or inconsequential to the overall planning process.

Many participatory models are criticized for not being truly collaborative and instead involving community members as "participants" while maintaining a top-down expert driven model for technology and planning delivery (Roma and Jeffrey 2010). Some examples of participatory research intend to adopt full participation methodologies but, according to Arnstein's typology, ultimately are limited to consultative studies that draw heavily from surveys, interviews, and focus groups (e.g., see Scott et al. 2008). Research studies where researchers enter a setting with the purpose of achieving certain research outcomes while gathering specific information from participants do not accomplish a redistribution of power (e.g., see Berardi and Donnelly 2008; Heaney et al. 2011; Scott et al. 2008). When interventionists intend to empower communities by giving them ownership over a system, ownership often means that the community members have served to inform researchers, who make the ultimate decisions about which projects are implemented, and community members are responsible for carrying out the projects in the long-term. Instead of being empowering, these projects are imposed upon communities by outside experts and are often unwanted by the communities.

Finally, the highest category of participation in Arnstein's typology is real citizen power. *Partnership* represents the first level in the spectrum where a redistribution of power begins to occur (Arnstein 1969). At this level, negotiation of the process is key and there is a degree of accountability for each member in the planning process. Citizens are able to influence the process. Partnership often comes from citizen engagement that demands accountability from decision-makers, wherein decision-makers are responsive to some of the citizens' demands, although power over decisions remains with decision-makers and not with citizens. With *delegated power*, citizens are members of boards and decision-making groups and have influence over the planning process. Citizens represent a majority of members on the boards but either an implicit hierarchy or external accountability to a larger power structure remains. With true *citizen control*, the form of participation with the greatest redistribution of power in favor of citizens, citizens have full decision-making authority and autonomy. Final approval rests with the citizens and no outside authority.

In translating Arnstein's typology to research on sanitation development projects, the highest form of participation would be where the target users represent fully collaborators in the co-production of knowledge about impaired living conditions and they have control over the substance and direction of the research study. Balazs (2013) provides a schematic of the transition from participant to study partner through degrees of participation, as shown in Figure 2.4. As indicated in the schematic, typical research methods adopt a helicopter approach where researchers "fly into" communities with research projects, conduct their studies, and "fly back out" with their data and no real contribution to communities. Often treatment interventions are short, with limited follow-up and no long-term investment by the researchers in the communities (Huicho et al. 2008). In "helicopter science" study participants have no influence over the study design, the interpretation of findings, or distribution of results (Balazs and Morello-Frosch 2013). In a community based participatory research (CBPR) study, participants are fully engaged in the research process, have influence over the study design, methods of data collection, interpretation and influence of results, and ownership of the data. While clearly not all scientific research can or should be conducted through citizen science methods, for research attempting to address and improve living conditions and enhance social justice for a targeted population, a participatory model is preferable.

In public health research, community-based participatory research is a well-established research methodology (e.g., see Wallerstein and Duran 2010). Lammerick et al. (1998) provide good examples of the execution of participatory action research to improve access to clean water in developing countries. In spite of intentions to include residents as participants in research, often researchers find that residents are unwilling or uninterested in participating in research studies related to the design and management of sanitation systems (Lopes et al. 2012). Little research exists on the co-development of water (MacDonald et al. 2013) or sanitation technologies. Information about how users are incorporated into interventions is not consistently shared. Further, studies of user acceptance to sanitation interventions often stay in the gray literature and do not reach peer-reviewed publications; sample participants for these studies are selected from samples of convenience and are not representative of general populations or even for the communities from which they are sampled (Lienert and Larsen 2009). MacDonald et al. (2013) found no other articles on water treatment technologies that were developed through a user participatory design process. Research instead focuses on technology efficacy, frequency of use, and proper usage techniques (MacDonald 2103).

Resource Recovery and Sanitation

Many efforts at developing resource recovery schemes through sanitation programs have attempted to address the core challenges of resource recovery and community participation that were established through the Bellagio Principles. In part, these efforts are intended not only to make projects more environmentally friendly and sustainable but also to make water and sanitation interventions meaningful for target populations by identifying resources and services that have value to them (Whittington 2009). These resources can include nutrients or soil conditioners from excreta for use in agriculture, nutrients from urine, water from wastewater, or gas from biofuels production.

Ecological sanitation is an approach to sewage waste management where sanitation is handled in a safe manner, is considered to be a non-polluting resource rather than a polluting waste product, and recycled products of sewage are used in the local environment to return nutrients and water to the ecosystem (Chaggu et al. 2002; Duncker et al. 2007). Ecological sanitation is a sustainable closed-loop system that treats human excreta as a resource, not as a waste product. Excreta are processed until free of disease organisms and the nutrients contained in the excreta may be recycled and used for agricultural purposes (Austin & Duncker, 2002). In developing countries, ecological sanitation may consist of source separating and composting latrines so that the end products can be easily transferred into agriculture or forestry (Austin et al. 2005).

In the late 1990s, an ecovillage in Sweden attempted to install several composting toilets but found that their performance was largely "disastrous" due to poor knowledge of the technology and poor instructions for their use (Fittschen and Niemczynowicz 1997). In the place of composting toilets, water toilets were installed. Surveys of potential users of recycling toilets in Nepal reported that 68% of those surveyed were not interested in having eco-toilets in their home and 39% said that the toilets might not be accepted at all (Pradhan and Heinonen-Tanski 2009). Even in China where use of nightsoil has long been used as an agricultural fertilizer, barriers to acceptance of source separating toilets remain (Medilanski et al. 2007). While surveyed stakeholders thought source separation is a good idea, many were reluctant to adopt the technology in their homes.

The use of excrement or wastewater as agricultural fertilizer has not been well received in spite of its promising future. A study of 467 Swiss farmers found that while there is demand for nutrients that can be recovered from wastewater, farmers were concerned about micropollutants, being responsible for cleaning up the waste burden placed on them from urban centers, and customers' perceptions of agricultural products fertilized with wastewater recovered nutrients (Lienert 2003). The farmers were reluctant to pay for fertilizer obtained from wastewater. A study in South Africa showed that people generally understood that excreta could be used as fertilizer, although they did not realize the same about urine. The authors concluded it was essential to change people's opinions towards human waste (Duncker and Matsebe 2008). Finally, while residents in Ghana recognized that human excreta could be used as agricultural fertilizer they refused to use it for their own crops (Mariwah and Drangert 2011).

Urine has more nutrients, including nitrogen, phosphorus, and potassium, than feces and urine is approximately 90% as efficient in nitrogen delivery as chemical fertilizer (Duncker et al. 2007). Some filtration methods, including nanofiltration and electrodialysis, have proven effective in removing micropollutants (e.g., pharmaceuticals or hormones) as part of urine separation (Escher et al. 2006). Urine source separation offers potential benefits in reducing nutrients that cause eutrophication in water bodies and reducing costs and energy for treatment (Tidåker et al. 2007). Acceptability of reuse of urine and feces for agricultural fertilizer varies widely throughout the world, with much greater acceptability of urine than feces reuse (Duncker et al. 2007). Urine reuse is practiced throughout the world and is widely practiced in Sweden (Duncker et al. 2007). Urine is typically associated with fewer cultural taboos than handling feces and it has fewer pathogens to cause harm. When properly stored, urine used as a fertilizer poses few risks for disease transmission (Höglund et al. 2002).

A number of studies have attempted to assess the acceptability of urine recovery technologies in different areas of the world. Perhaps the best-studied reuse technology is the NoMix toilet which has been developed at Eawag in Switzerland. Researchers surveyed 1,249 visitors and employees of Eawag, an organization that is very supportive of urine source separation technologies (Lienert and Larsen 2006). NoMix is a urine-separating toilet that requires men to sit on it to urinate, which poses some reluctance among men. Of surveyed men, 72% were willing to sit on the toilet but 28% of the men preferred not to sit on the toilet. Men and women were also uncomfortable with disposing of toilet paper in a bin outside of the toilet. In a review of thirty-eight NoMix projects in seven European countries, researchers found that while 80% of users liked the idea of NoMix toilets, 60% had problems with its actual use and most were less likely to be accepting of NoMix toilets in their own homes (Lienert and Larsen 2009). Focus groups in Switzerland found consumers liked the possible environmental benefits of NoMix but did not want to have to pay extra for it and had concerns about micropollutants in nutrient recovery (Pahl-Wostl et al. 2003).

Other urine diversion toilets have faired similarly. In Germany a study found that users of urine diversion toilets appreciated the concept but were unhappy with the inconveniences associated with the toilet's use, had concerns about how sanitary the toilets were, and disliked the extra maintenance and cleaning they required (Blume and Winker 2011). Thousands of urine diversion dry (UDD) toilets have been constructed in South Africa. A schematic of a typical UDD toilet is shown in Figure 2.3. Studies of households with UDD toilets in South Africa show that 16% of households do not use installed UDD toilets as toilets and 86% were unwilling to handle their own excrement in cleaning the toilet vaults (Anonymous 2005). Another study of UDD toilets in South Africa found that residents did not like using the toilets because they felt that they were unsanitary, uncomfortable, smelled badly, embarrassing to explain to guests, and expensive (Matsebe and Osman 2012).

Another approach to resource recovery is through biofuels. Biofuels are considered by some to offer a strong future for resource recovery in the developing world but even studies that envision their implementation in specific geographic regions in the developing world often fail to consider social factors or user acceptability in their technology design (e.g., see Bond and Templeton 2011, Mshandete 2009, Nzila et al. 2012). More research is needed on the social acceptability of biofuels in developing countries as well as whether they can provide a resource that meaningful to users.

In spite of efforts to bring sustainable, resource recovering technologies to poor communities with inadequate sanitation, these projects have been criticized by poor communities and poor advocates for failing to account for actual communities' needs and desires and instead pushing a specific sanitation intervention agenda that is held by NGOs, policy makers, and technological experts (Hendriksen et al. 2012). Communities do not necessarily automatically have demand for waste recovered nutrients nor do they automatically prefer such fertilizer options over paying for chemical fertilizers, which do not require handling human excrement. Ignoring user needs and preferences has led to widespread failures even in resource recovery sanitation interventions (Hendriksen et al. 2012).

Poverty and Sanitation

Many development perspectives adopt the viewpoint that population growth is the primary determining factor for poverty and environmental degradation (Commoner 1994; Ehrlich 1968; Ehrlich and Holden 1971; Hardin 2001a; Hardin 2001b; Malthus 1798/1998) and not that political and structural inequalities differentially impact vulnerable populations (Bullard 1993; Bullard 2001; Colten 1989; Elkind 2006; Johnson et al. 2004; Litt et al. 2002; Ringquist and Clark 1999; Swyngedouw 2004; Swyngedouw 2011; Torres-Rouff 2006). Using an assumption that population is the core challenge facing the management of water and sewerage a logical conclusion is that the solution to impaired water and sanitation is better, lower cost, and more efficient treatment technologies that can be delivered at increasingly large scales. Some argue that sustainable development and environmentally friendly innovations will be key in reducing poverty in developing countries (Khavul and Bruton 2013). These perspectives align neatly with others that argue that merely through behavioral change of the target recipients, educational and capacity building activities poverty can be reduced or eliminated directly. Poverty, however, is complex and is tied not only to material resources and motivation but also to social and political inequalities that shape opportunities in each setting.

Impaired sanitation access is tied to conditions of poverty that require more than just engineered solutions (Murphy et al. 2009). According to the World Bank (2014), roughly 1.22 billion people in the world live below $1.25 per day and 2.4 billion live below $2 per day, which in 2010 represented 35% of the world's population. Measuring poverty across settings is difficult and lack of access to water and sanitation is one way of operationalizing poverty (Biltonen and Dalton 2003). Complicating matters, lack of clean water and sanitation are contributing factors to poverty (Hendriksen et al. 2012). Living in poverty, lack of clean water and sanitation leads to increased risk of diseases which lead to health effects that impact DALYs, thus suppressing wellness, life expectancies, and earning potentials (Ruffin 2010).

Not only does poverty lead to resource impairment, it also is a mechanism for stratifying social groups. This stratification leads to power differentials in local communities and limited access to opportunities that could improve living conditions. Awortwi (2012) looked at why residents do not participate in community development projects and found that relatively more affluent community members tended to participate more readily in projects. Consistent with this finding, Kumar et al. (2013) found that children in lower socioeconomic statuses and girls were less likely to experience reduced diarrhea from sanitation interventions.

Failed sanitation interventions can be due to the low social status of those with impaired sanitation access, lack of political will, little public awareness to the extent of the problem, poor policy and institutional structures, discounting or dismissal of user needs and preferences, or contextually inappropriate strategies (Eawag 2005). Luoto et al. (2011, 2012) compared acceptability of four different water treatment technologies and found that adoption did not have as much to do with cost, education, or individual technology features as expected and instead had to do with other social factors that were not adequately considered in the interventions.

Addressing impaired water and sanitation access requires an appreciation for and deep attention to the complexity of constraints that lead to impaired access (Smith and Martin 2005). In particular, social constraints often defy easy quantification and can frustrate those seeking parsimonious models. Some of the kinds of social constraints that defy simple explanations include violence, trust, community organization and cohesion, and local and regional power inequalities.

As well, certain cultural expectations may conflict with the cultural expectations of those attempting to implement interventions. Neoliberal perspectives affirm economistic models of public goods but not all cultures ascribe to this same frame. In many cultures, water is valued as a public good and the public typically considers this to mean that water should be freely available. Such communities are reluctant to adopt payment models for water and sanitation services. For example, the national government of Tanzania began delivering water to rural communities in the 1940s (Jiménez and Pérez-Foguet 2010). In 1965 the Tanzanian government decided that water should be a free public good but that local governments should pay for infrastructure maintenance. Delivery of water infrastructure in rural Tanzania has been hampered by poor quality and inconsistent quantity of the water delivered; limited sustained investment of financial resources; inadequate investment in community capacity building; inequitable distribution of projects, particularly to communities and community groups that lack political influence; and lack of information sharing about system functionality and efficacy.

Similarly, South Africa has a national policy that water is a free public resource but this does not include the infrastructure (Ashipala and Armitage 2011). There is substantial disagreement about what exactly in water delivery is free and this leads to conflict with government programs and those seeking to develop water improvement systems. Balancing the need for financial resources for the operation and maintenance of water and wastewater systems with the expectation that water is a universal human right can present ideological conflicts in development projects.

Some of the challenges to the sustainability of improved water and sanitation include availability of affordable resources for systems such as technically skilled workers and materials for construction; adequate operation and maintenance of technologies; proximity of target communities to other available infrastructure; costs of equipment, resources, and labor; knowledge about disease and the need for proper sanitation; trust of systems, technologies, local leadership, and interventionists; and availability of long-term financial support for development projects (Montgomery et al. 2009). Carrying out sanitation interventions cross-culturally requires nuanced and respectful attention not only to the cultural values that target populations carry but also to the values that are imposed by interventionists through their efforts to improve the lives of others likely immersed in vastly different life frames.

Power and Expertise

Traditional scientific research involves an inherent power dynamic between the researcher and the research participants that often goes unacknowledged by researchers (Balazs and Morello-Frosch 2013). Interventions that rely on expert-driven models ultimately deliver specific technological and economic belief systems to local governments and NGOs with no place for actual end users to shape their own life practices (Hendriksen et al. 2012). Well-designed participatory research methods can address this power inequality and result in colearning and a co-production of knowledge, with a more democratic power structure that addresses the concerns of community participants and not just researchers (Balazs and Morello-Frosch 2013). However, even when researchers are able to break down hierarchies between researchers and participants, interventions must still contend with power differentials between researchers, end users, and local power structures (Swyngedouw 2013).

Sociologists have argued for a more democratic form of science that recognizes that science is not value free and objective and that the process of creating and selecting information to become facts is influenced by numerous social factors (Kelly and Farahbakhsh 2013). The process of establishing certain expert forms of knowledge as singular truth displaces other forms of lay knowledge as ignorance and backwardness (Thrupp 1989). In particular, actions that are considered ‘common sense’ are value laden with normative structures embedded within particular cultural settings (Geertz 1983). As technology is associated with modern, civilized society, the rejection of technological interventions is seen as not merely a rejection of the intrusion of outsiders into private settings but a rejection of modernity itself (Murthy and Mani 2013). Interveners perceive rejection of technology as evidence of backwardness. Valerie Kuletz (1998) said that “Western science [is a form of] ethnic knowledge production with its own ethnically based representational forms” (p140). To her, Western science represents a culture, wherein it holds a specific “*cultural* representation of nature” (Kuletz 1998, p141). Viewing science this way, we can see that science represents the domination of one culture over another.

According to sociologists, knowledge is something that is formally agreed upon by a body of people (Bloor 1976). Knowledge undergoes a process of legitimation by a collective body which is structured through power relations and power inequalities that filter what kinds of information are allowed to become formal knowledge. Feminist science studies scholars have argued for a critical understanding of knowledge production where knowledge is not singular but multiple and situated knowledges derive from particular social locations, biases, experiences, and sets of assumptions (Haraway 1991). Donna Haraway (1991) has argued that scientific practice occurs within a limited gaze that sees the world as abstract and highly specific but which is taken to be universal and complete. The inclusion of non-dominant perspectives, or subjugated standpoints, allows for greater accountability in forms of knowledge produced and a redistribution of power over what is considered truth.

To demonstrate the social construction of knowledge, David Bloor (1976) examined mathematics, which is considered to be the most uncontestable and universal language of knowledge that humans possess. Bloor demonstrated, however, that certain decisions were made along the way in determining the structure and priorities within mathematics that have fundamentally shaped the way that humans think about and understand mathematics and physics today. Bruno Latour and Steve Woolgar (1986) looked at the social construction of what constitutes scientific 'fact' by conducting an ethnographic study of a molecular biology laboratory. Latour and Woolgar argued that the concept of 'fact' itself needs to be examined though a sociological lens as something that is produced and validated socially. They made clear that the purpose of their endeavor was not to argue that there is no objective reality to 'facts' but rather that the notion of a fact is socially constructed. They sought to examine the social process through which this construction of fact takes place. "Reality," they said, "is the consequence of debate" (Latour and Woolgar 1986, p182). Additionally, they viewed this process of fact construction as ultimately removing all traces that a fact was socially constructed in the first place. Latour and Woolgar said that once a fact becomes stabilized and accepted as a fact, an inversion takes place wherein the statement about a fact becomes what is accepted as reality. This allows for accepted facts to be taken for granted as truth, unless and until they are later contested—in which case, the constructed nature of the fact re-reveals itself.

Sanitation represents a particularly unique area of study because it entwines biological processes of pathogen transmission, health effects of pathogens, environmental transmission and cycling of nutrients and contaminants, organization and management of water and wastewater infrastructure, financial resources and costs, and cultural and moral values related to bodily practices and handling of human waste. One-dimensional analyses tend to focus on the knowledge produced within each situated dimensional of sanitation while struggling to account for other frames and analytic strategies for explaining limited sanitation conditions in poor communities. Sociologists draw focus to this contention thereby providing an interpretation for why sanitation interventions are so challenging to execute effectively.

Conclusion

Although recognition of the need for international, cooperative efforts at reducing poverty and improving access to clean water and sanitation has been present throughout the latter half of the twentieth century, the International Drinking Water and Sanitation Decade during the 1980s, the Bellagio Principles in 1996, and the Bellagio Principles for Sustainable Sanitation in 2000 set the stage for targets set forth through the Millennium Development Goals in 2002 to reduce by half the number without basic sanitation.

In spite of international calls for the development of sustainable sanitation programs, widespread adoption of sanitation technologies and interventions has been limited. Different approaches to sanitation interventions, including the appropriate technologies movement (which emphasized small scale and locally appropriate technologies), the shift from hardware to software (which emphasized intangible social factors over technological interventions), and the participation thrust (which reignited calls for cooperative and collaborative sanitation project development), each attempted to address shortfalls in user acceptance of development initiatives.

Many aspects of each of these frames overlap and are complementary with one another, but in practice each has at times fallen short of creating the kind of locally situated implementations necessary for long-term sanitation improvement sustainability.

In particular, weaknesses in each of these approaches lie in the oversimplification of poverty and its causes as well as uncritical approaches that fail to consider how development projects and technologies themselves (as well as the researchers and interventionists who promote them) are also situated within social contexts that interact with and at times reinforce social contexts that lead to substandard living conditions in poor communities. Sociologists call not for an abandonment of scientific objectivity but a critical awareness of how the production of facts related to the wellbeing of poor populations, in particular, is limited in its gaze towards the complex challenges faced under conditions of poverty. Given its complexity, some have argued for the importance of drawing from several disciplines to inform the best intervention techniques for improving sanitation (Elliott 2011). In the next chapter, we explore how engineers draw from interdisciplinary perspectives to inform their role in sanitation technology innovation.

CHAPTER 3

BIBLIOMETRIC ANALYSIS

Keywords: Sanitation, Technology, Design, Users, Participation, Developing Countries

Introduction

Providing access to basic sanitation for all people throughout the world has been an international development goal at least since the 1948 formation of the World Health Organization's Expert Committee on Environmental Sanitation (WHO 2003). With the period from 1980 to 1990 declared the International Drinking Water Supply and Sanitation Decade significant investments have been made in attempting to provide universal coverage for basic sanitation (Jiménez and Pérez-Foguet 2010). It was during this decade that the Brundtland Report, which was commissioned by the United Nations, declared that in order to maintain long-term health and economic opportunities for humanity, international development efforts need to shift to a sustainable framework (Dryzek 1997). Sustainable development, as defined by the Brundtland Report, is a process of development that does not sacrifice future populations' ability to meet their own needs. With the declaration of the Bellagio Principles for Sustainable Sanitation in 2000, it was firmly established that providing universal access to basic sanitation is a key feature of sustainable development efforts (Lüthi et al. 2007).

In spite of recognition that providing basic sanitation enhances the wellbeing of both present and future generations, efforts to deliver sanitation technologies and to transform hygienic practices have had limited success. As much as 2.5 billion people worldwide lack access to basic sanitation facilities and as of 2011 15%, more than 1 billion people worldwide, practice open defecation (WHO 2012a, WHO 2013). Although gains have been made (from 2.8

billion without sanitation in 1990 to 2.5 billion in 2010), goals for reducing the percentage of the world's population without basic sanitation have fallen short (WHO 2012a). Additionally, even with these improvements due to the effects of climate change the incidence of diarrheal disease is expected to increase at least by 10% by 2030 (Shuman, 2010).

With sanitation numbers falling short of target goals, actors working towards improving access to sanitation need to step back to evaluate what role they play in the success and failure of intervention projects. Engineers, as drivers of technology development, must consider how sanitation technologies have been successfully implemented and where they have failed. Key in this process is understanding the roles that target users of sanitation technologies play in sanitation technology development and in sanitation improvement interventions. While international development literature has long emphasized the importance of user participation in development efforts, engineers have struggled with how to engage local populations in sanitation innovation. With this paper we ask: how have engineers incorporated target users into sanitation technology design strategies? To answer this question we conducted a bibliometric analysis of sanitation literature focusing on user inclusion in developing countries.

Sustainability research is inherently interdisciplinary and is becoming increasingly so over time (Schoolman et al. 2012). As well, sanitation is a complex social problem that requires a multifaceted approach (Hendriken 2012; Murphy et al. 2009; Smith and Martin 2005). Those working towards sanitation improvement projects in developing countries must draw from a range of resources to engage with that complexity and to situate their work within in. We are particularly interested in how engineers engage with interdisciplinary scholarship to inform mechanisms of working with target populations to shape processes of technology design. By detailing the coherence of engineering literature targeted at improving sanitation in developing countries, we aim to be able to describe the topography of the literature and identify where important gaps and disconnects exist that may provide fruitful avenues for enhancing engineering strategies for working with target users.

Pablo Catalan and Susan Cozzens (2009) conducted a bibliometric analysis of water supply and sanitation that looked at articles publishes in Web of Science between 1998 to 2008. They examined frequency of publications by year, country of origin, number of collaborations in the publication determined by author affiliation, and international collaboration by global North and global South linkages. The overall findings of this analysis were that most publications originated from North American (36%) and Europe (29%), with the most publications coming from the United States, specifically. More than 40% of studies involved only one organization and more than 75% involved two or fewer, but the trend appeared to be towards increasing collaborations. Little collaboration occurred between global North and South countries, but number of North-South collaborations, particularly with developing countries in Asia, were increasing over time.

No comprehensive analysis that we could find conducted an in depth examination of citation data from searches looking at sanitation interventions. A bibliometric analysis of citation data offers the advantage of considering how publications speak to each other across an interdisciplinary topic area. Ismael Rafols and Martin Meyer (2010) state that this type of analysis helps to look at diversity of disciplines in a given topic area as well as coherence between these disciplines. Diversity characterizes the different types of disciplines or topical areas represented while coherence is the extent to which the data are related to each other. For an interdisciplinary topic, an ideal scenario is to see both high diversity as well as high levels of coherence but lack of either is informative as to where opportunities for the development of new research areas exist.

Figure 3.1 shows the theoretical distribution of network coherence and diversity as given by Rafols and Meyer (2010). In the case of low diversity, the data draw exclusively from a single area or discipline while with high diversity multiple disciplines are represented, as indicated by different colors and shapes in the figure. With low network coherence few or no linkages connect different topical areas within the broad topical area that the data cover. With high network coherence multiple linkages connect publications across the data. The case of low coherence but high disciplinary diversity offers the opportunity to identify potential linkages that are currently underutilized.

This paper focuses on how engineers draw across disciplines to inform techniques for incorporating users into sanitation technology design. Because few techniques exist within engineering for addressing social factors, we expect to see high levels of interdisciplinarity as engineers draw from other disciplines as to how to engage with target users. As well, sanitation literature is highly interdisciplinary so this would add to the degree of diversity in our findings. Since social factors are challenging for engineers to address, we expect to see high levels of atomization and little network coherence. In identifying areas with high diversity and low coherence, we hope to inform the literature as to where for further sanitation research opportunities exist. Before presenting our bibliometric analysis, we begin with a review of the dominant engineering approaches to user inclusion as described in the literature.

Engineering Approaches to User Inclusion

Traditional engineering approaches to technology design involve client consultation as needed but do not treat users as active participants in the identification, selection, and design of solutions (Murphy et al. 2009). Often technologies for poor water and sanitation conditions in low-income settings are developed in complete exclusion to target populations with just a cursory acknowledgement that social factors should be considered at some point (e.g., see Mwabi et al. 2012). User preference for water and sanitation technologies during interventions is typically garnered through brief studies using household surveys of preferences, self-reported usage, and measurements of treatment efficacy during the study period. Studies that are declared to be successful frequently have had short-range or no follow-up periods to be able to assess long-term intervention success (Starkl et al. 2013). Further, studies of user acceptability typically only examine features related to technology use and not larger social factors that may inhibit or take priority over intervention adoption (Albert et al. 2010).

When engineers have attempted to allow users to influence technology planning and design, they have relied on a few specific strategies for incorporating users into technology development. These principle schemes have included appropriate technologies, user-centered design, multiple criteria decision analysis, and participatory action research. Each of these approaches has an established tradition in the literature as well as specific ways in which it goes about addressing users in the process of development interventions.

Appropriate Technologies

Appropriate technologies is a response to the efforts to transfer technologies from Western research contexts to the developing world. Appropriate technologies involves the development of technologies that meet specific criteria for use and acceptability in the target setting. One example of an attempt at an appropriate technology was an effort to develop an improved, low-cost latrine system for women in Nepal (Murphy et al. 2009). This was a low-technology solution but did not rely on women's participation in the development of the project. Ultimately, the project failed because it did not meet the women's needs and because it failed to operate to treat waste as it was intended to do. Another much more successful effort at appropriate technology development has been the Sulabh toilet model (Ramani et al. 2012). The

Sulabh toilet is an alternating pit system that allows excrement to compost in an unused pit while a second pit is used to collect waste. In India, the Sulabh toilet has worked well and has experienced broad acceptance in dry climates, where it functions properly. In wetter areas urine diversion dry (UDD) toilets are used to reduce the water content in the system.

Figure 3.2 shows a model for the diffusion of appropriate technologies. According to Ramani et al. (2012), standard appropriate technologies approaches begin with user surveys to assess the need for the technology, willingness to pay for it, and availability of resources to support maintenance and operation. Next, an appropriate technology is developed or identified by interventionists, which is followed by awareness raising and educational campaigns through workshops, games, and face-to-face discussions. In implementing the sanitation intervention, target households are selected by interventionists to serve as pilot households which will demonstrate the technology to the larger community. Some approaches will go beyond the most basic delivery stage and will continue an iterative process to ensure fit (Ramani et al. 2012). Following delivery of the technology, interventionists will provide incentives for use such as personalization, celebrations, or ongoing troubleshooting support. In these continuing projects, ongoing monitoring of efficacy and usage is performed along with continued educational and promotional campaigns.

In summary, the appropriate technologies approach is a principally top-down approach where interventionists identify communities that may be in need of basic sanitation. Through surveys or focus groups, interventionists collect information about technology need and begin to identify technologies that the interventionists believe will provide appropriate solutions. Interventionists select participants to receive technologies; appropriate technologies projects have no inherent mechanism in them to redistribute power and decision-making to target users.

Promotion of appropriate technologies interventions is carried out through educational, behavioral change, and marketing campaigns.

User-Centered Design

User-centered design was popularized through the work of Donald Norman (Abras et al. 2004). Norman's (1986, 1988) recommendations situated the user at the center of the design process allowing for user input and redesign at each stage of development. User-centered design consists of four phases: the analysis phase, the design phase, the implementation phase and the deployment phase. This approach involves gathering information about how the technology will be used, in what context it will be used, and the specific user needs for the technology. Information gathering can be through focus groups, usability testing, questionnaires, and interviews. Next the technology is designed and user feedback is solicited regarding the usefulness and value that the technology has to the user. Participatory design processes may include having target users develop prototypes or role-play use of the technology. During the implementation phase the technology is delivered at a limited scale and it is beta-tested to evaluate how its functionality meets the needs of users. Finally in the deployment phase continuing solicitation of feedback is conducted to inform usability of the product.

Figure 3.3 shows the user centered design process as it has been standardized in ISO-13407 in 1999 and ISO-9241-210 in 2008 (Lindström and Malmsten 2008). Figure 3.3 emphasizes that user-centered design is an iterative process based upon interaction with target users and ongoing usability testing. User-centered design adds increased cost and time to development, may require additional staff on the research team to work with and collect data from potential users, and the final design may be a highly specific product that has little generalizable marketability (Abras et al. 2004). User-centered design is a process that is driven by design engineers who retain control over the project but for which the process of making decisions is heavily informed by user preferences. Although participatory elements are key to user-centered design, ownership over the product and its goals remain with the developers. User-centered design is used in particular for software development and does not appear to be widely exploited in water and sanitation technology development.

One study in South Africa used an approach similar to user-centered design to develop a planning model for water resources management. Like user-centered design, the Adaptive Decision Making Process (ADMP) uses a user-focused approach that involves iterative policy redesign through stakeholder interaction (Lal et al. 2001). The ADMP, as shown in Figure 3.4, involves identifying the specific challenge to be addressed and the available resources, developing a plan of action and communicating with stakeholders about what priorities are shared, carrying out the action plan, and finally iteratively learning about challenges and modifying the project design and implementation.

Armitage et al. (2009) used an ADMP to work with community members to develop a greywater management system. The ADMP used a consultative model that worked iteratively with community members to find a reasonable greywater management solution (Armitage et al. 2009). The intent of the greywater project was not to provide an "appropriate technology" that could meet ideal conditions in the setting but to provide an action plan for a transitional project that could mitigate crisis sanitation conditions until the local government could provide adequate sanitation infrastructure. Armitage et al. (2009) found that in attempting to carry out their study many residents did not participate and waited for the research team to deliver the results of the project. Further, when residents did participate, the research team viewed the residents' efforts as improper and unsanitary. Challenges with local politics and distrust between residents, researchers, and political leaders ultimately led to limited cooperation. These challenges were exacerbated by the fact that management of greywater was a low priority for residents.

An ADMP approach is similar to a UCD approach in that the project is designed around stakeholder participation to inform strategies of action. Where UCD is principally a technology design strategy, ADMP can be used for technology design as well as for behavioral interventions and educational campaigns. Like UCD, though, ADMP does not redistribute power within the study design but uses a consultative model to achieve the goals of the intervention. The Armitage study attempted an intervention on greywater, which was of significance to the research team, but because greywater was of limited importance to residents, significant distrust was present in the setting, and the researcher attempted a top-down sanitation intervention success using the ADMP in this context was minimal.

Multiple Criteria Decision Analysis

Multiple criteria decision analysis (MCDA) has a long history and there are dozens of published approaches for going about an MCDA (Hwang and Masud 1979, Kalbar 2012b). In general MCDA is a mechanism for modeling decisions based upon a weighting of factors considered relevant to the outcome of the model. Theoretical (e.g., from literature), empirical (e.g., from surveys or focus groups), modeling (e.g., from life cycle assessment for environmental impacts or life cycle costing), or standards of practice data are collected on each of the factors. Each factor is then assigned a score based upon perceived benefits or impacts that the factor has on the outcome. Modeling is then used to maximize perceived benefits and minimize negative effects.

Multiple criteria decision making is a tool that has been used to decide between different wastewater treatment options principally in assessing urban treatment options (Kalbar 2012a). Using multiple criteria decision analysis for water and sanitation ideally includes technical, social, economic, and environmental criteria (Garfi and Ferrer-Martí 2011). Operationalizing social factors, however, is complex and some researchers choose to leave this out of their design process entirely (e.g., see Nzila et al. 2012).

Borsuk et al. (2008) used multiple criteria decision analysis to explore opportunities related to the development of NoMix toilets. The researchers considered end-users, plant managers, engineers, equipment manufacturers, farmers and research scientists as stakeholders. By speaking with key stakeholders the researchers quantified concerns about use in the analysis in order to develop a plan for what they viewed as the best possible recommendation for moving forward with the implementation of NoMix toilets.

Hendriksen et al. (2012) elaborated on a participatory method of multiple criteria decision-making, which they called Proact 2.0. Proact involves engaging multiple levels of stakeholders in problem identification, and setting objectives and alternatives, with pros and cons assessed for each option. Planning for Proact involved working with a familiar set of technologies and engaging residents in workshops to identify the most favorable solution. Hendriksen et al. used MCDA in this case to carry out a participatory planning process for making sanitation improvements.

With an MCDA approach, it is typically viewed that sustainable solutions are achieved through proper selection of technologies (Kalbar 2012a). Some of the criteria that can be used in selecting technologies are affordability, acceptability, and manageability (Kalbar 2012a). Figure 3.5 shows a process for selecting appropriate technologies according to what is described by Kalbar et al. (2012a, 2012b) as a Multiple Attribute Decision Making framework (MADM). Within this framework a set of alternatives is considered along with specific indicators which are key measures of the success of those alternatives. Data is collected to create weights for those measures. Factors such as costing, sustainability, reliability, and acceptability are included in the model. The outcome of the model is a rank ordering of the possible alternatives.

Unlike the appropriate technologies and user-centered design frames, MCDA is not necessarily an iterative process. MCDA is used to select the best option from a set of predefined options. Like appropriate technologies and user-centered design, MCDA is a top-down approach to decision making. Again, while input may be solicited from target users they are not co-producers of knowledge related to intervention design and execution.

Participatory Action Research

Participatory action research (PAR) is credited to Kurt Lewin (1947). PAR was developed as a social research methodology that could serve as a mechanism to disrupt hierarchical and expert driven study designs. PAR emphasizes the coproduction of knowledge and redistribution of power away from researchers to community participants. Figure 2.4 shows a spectrum of participatory models in scientific research where traditional "helicopter science" is at the lowest end of the spectrum in terms of equitability between the researcher and the participant while PAR emphasizes power sharing and collaboration between researchers and participants.

Key features of a PAR approach include developing an initial plan for change, executing the plan, reflecting on the process of execution, developing a new action plan and so forth (Kemmis and McTaggart 2005). This process of research is referred to as the action research spiral. Like appropriate technologies and user-centered design approaches, PAR is focused on the participants and the communities in which interventions are intended but unlike appropriate technologies and user-centered design PAR emphasizes sharing of power, communication, and transformative exchanges that impact not only participants but the researchers as well.

A study in Bangladesh used PAR to work with 400 communities to end the practice of open defecation (Ramaswami et al. 2007). This project involved engaging community members in community mapping to raise awareness of the spaces that were used by community members and how they were used, quantifying the contribution of feces to the local environment, teaching villagers about disease transmission pathways, building community consensus about the need to end open defecation, and engaging community members in research and designing their own toilet systems.

Another study looked at efforts to develop a household water filtration system through a five-stage participatory action design (MacDonald et al. 2013). The researchers invited community leaders and members to participate in a water treatment co-design process where the only condition for participation was interest. The researchers held six workshops, each with eight to ten community residents and three to four researchers. Together they worked to develop a filter design that met community needs and had a reasonable level of treatment.

In practice, carrying out a true PAR approach is rare and difficult for researchers to execute. Disciplinary and funding demands typically restrict the direction of research and present significant obstacles to PAR methods. Many studies do attempt varying degrees of participation with community members, which may or may not include power sharing over the direction of the research. Very often, though, participation is used as an incentive for achieving the researcher's goals rather than as an attempt to promote justice for participants.

An initiative for school-based prevention of schistosomiasis was originally interested in children's knowledge about schistosomiasis, but the researchers found that the teachers acted as gatekeepers, preventing the researchers from reaching their goals (Freudenthal et al. 2006). By involving teachers as full partners in the research and design process the study was ultimately more successful in achieving the researchers' goals.

In another study of cocoa farmers, participatory methods meant educating farmers on epidemiology and pest control so that farmers were able to utilize that knowledge in controlling their own crops (Daniel et al. 2011). The researchers found farmers who used the information had decreased pests and diseases and that crop yields increased 30%. Farmers were encouraged to share their knowledge with other farmers, and the educational program became a national model for improving cocoa production. While this study was self-described as participatory, in truth participation was limited to education of and marketing to farmers to change their practices.

Although not enhancing power redistribution, the concept of demand driven engagement has been used as a way to avoid bringing interventions to communities where the interventions are unwanted. Demand driven approaches emphasize that projects need to be wanted by the communities and that target users need to be willing to pay for services delivered (Whittington et al. 1998). The demand driven model asserts that water is an economic good and not a public good. Demand driven planning utilizes a rapid appraisal approach to assess demand in a target community, which allows for quick needs assessment but sacrifices rigorous sample selection methods. Demand driven approaches in fact are not participatory action projects but they do get described as participatory projects because they seek to have community engagement in order to bring interventions into communities.

Household-Centered Environmental Sanitation (HCES) is a participatory sanitation approach that emphasizes the role of users in the planning process for sanitation interventions (Lüthi et al. 2007). The HCES method derives its origin from the 2000 Bellagio Principles for Sustainable Sanitation and is unique in setting the household and its immediate community as the target of intervention, rather than specifically identifying appropriate technological solutions for perceived risks (Eawag 2005). The target audience for an HCES approach is the local community leadership who would be responsible for administering any community-level intervention, with local NGOs or regional stakeholders as secondary audiences (Eawag 2005). HCES attempts to be an intermediate level intervention that mobilizes multiple levels of stakeholders (Eawag 2005). Consistent with the 2000 Bellagio Principles for Sustainable

Sanitation, HCES aims to improve the quality of life of those living in marginalized conditions and to treat excreta and wastewaters as reusable resources (Eawag 2005).

HCES involves a ten-step process, as shown in Figure 3.6, which begins with a request for assistance, progresses through planning, evaluation of options and alternatives, implementation, evaluation, and iteration. With the emphasis on participation within the HCES frame and the iterative decision making process, HCES is somewhat of a bridging approach between PAR and ADMP. Unlike a PAR method, HCES does not address potential conflicts with local power arrangements and how researchers participate in those power relationships through intervention in local communities.

Summary

A number of different approaches are available to engineers interested in developing sustainable sanitation interventions and there is precedent for each of these approaches in the literature. Still, most sanitation interventions rely heavily on top-down educational frames that seek to change user behaviors. They do not tend to work with users to collaboratively identify solutions to the problems that users identify in their own communities.

Of the methods for incorporating users into sanitation interventions, only multiple criteria decision analysis does not involve an iterative design process that engages with target users in a sustained fashion. Researchers have, however, made use of MCDA to develop new techniques, such as Proact 2.0, to develop quantifiably objective strategies for selecting optimal interventions.

Only the appropriate technologies approach explicitly emphasizes technologies as the best approach to addressing challenges related to poverty and sustainability. While appropriate technologies does seek to find technologies that are the best fit for communities, the appropriate technologies frame relies on a model that imposes a technological solution to challenges that require more nuanced action plans.

While user centered design does not appear to have made inroads into sanitation technology development, the adaptive decision making approach, which draws from a user-centered design approach, does provide for community-level engagement in sanitation interventions. Similarly, Household Centered Environmental Sanitation is also modeled from user-centered principles.

Participatory Action Research, with goals to bring about transformative change and reduction of power differentials between interventionists and community members, offers the most equitable approach to poverty interventions. Given the constraints that academics face in designing and carrying out research, however, for many researchers PAR is unrealistic. Still, PAR does draw attention to the relationship between researchers and participants and awareness of PAR may support more reflective praxis in sanitation interventions.

The identification of these approaches to user inclusion in sanitation interventions provides a foundation from which to build our analysis of the literature related to engineering approaches to sanitation in developing countries.

Methods

To assess the distribution of literature on how engineers engage with sanitation improvement interventions in developing countries, we identified a set of sanitation and user criteria that would narrow our search to this specific topical area. In addition to our two primary search areas, we identified three other filters (development, engineering, and hospitals) to narrow our focus. Beginning with literature on sanitation, we selected key terms that would collect a wide sample of documents from the literature. The exact phrasing of our Scopus search is presented in Appendix C. The sanitation terms that we identified included sanitation, wastewater, “waste water,” sewage, excrement, blackwater, “night soil,” feces, faeces, sewer, or urine.

Secondly, through our initial survey of the literature we had already identified appropriate technologies, user-centered design, multiple criteria decision analysis, and participatory action research as significant mechanisms for incorporating target populations into design strategies. With this as our base, we selected a user-focused subset of data. The terms that we included in this search were “user-centered design,” “user centered design,” “user-centred design,” “user centred design,” “participatory action research,” “community-based participatory research,” “community based participatory research,” “appropriate technologies,” “action research,” participatory, “multiple criteria decision analysis,” “multiple criteria decision modeling,” “household centred environmental sanitation,” “household centered environmental sanitation,” “community-led total sanitation,” “community led total sanitation,” “bottom-up innovation,” “bottom up innovation,” “stakeholder participation,” “local knowledge,” “public participation,” “social learning,” “traditional ecological knowledge,” “traditional knowledge,” or “sustainable development.”

Since our interest area is in sanitation interventions for communities living in poverty, we narrowed our sample to the developing world: “develop* countr*,” “developing world,” “third world,” “less developed countr*,” “less-developed countr*,” “developing nation*,” “less developed nation*,” “less-developed nation*,” poverty, “economically disadvantaged,” “low income,” “low income,” or “millennium development goals.” As well, our focus area is on how engineers incorporate users into design strategies so we further limited our sample to include engineering, engineer, engineers, or technology. Lastly, we selected articles published from 2000 to 2013 and only articles, articles in press, or books. Initial searches revealed that a selection of articles referred to hospital sanitation procedures and nosocomial infections so our final filter excluded references that included the word “hospital.”

In order to identify the largest available subset data, we compared the search across Scopus, Web of Science, JSTOR, and Google Scholar. Scopus provided the largest dataset so Scopus was selected as the source of citation data. Although multiple programs are available to organize data from Web of Science (e.g., Bibexcel and Sitkis) and Google Scholar (e.g., Publish or Perish), we were unable to identify an adequate resource to process data downloaded directly from Scopus. As such, we developed a novel MATLAB script to organize data downloaded from Scopus in a manner sufficient to import into Pajek (Batagelj and Mrvar 2008) for network analysis. The advantage to the MATLAB script, which we have named Synapse, is that we are able to have control over data cleaning, process quality, and we are able to continue to make improvements in the Script to improve our match rate. Synapse is able to accept a large data file downloaded from Scopus, disaggregate the references, assign an ID number, and match the files in order to create a unique identifier for all articles and references in the dataset. The data are then structured so that they can be imported directly by Pajek as a .net file for network analysis.

Synapse must overcome a number of challenges to improve the quality of the data downloaded through Scopus. While the primary articles searched for have consistent citation formatting, references within those citations do not. We refer to the articles that were retrieved directly in our search as primary sources and to their references as secondary sources. Articles may have complete author first names, middle names, or abbreviations. Journal names may be abbreviated but for this there is no consistent format. While all primary articles originally searched for in Scopus were articles, articles in press, or books, references for each citation can come from any cited source ranging from peer-reviewed publications, books, conference proceedings, and industry reports. These sources are much more inconsistent than articles in their formatting, which increases the complexity of matching.

Synapse takes ASCII formatted data downloaded from the Scopus database and collects citation information (authors, title, publication year, journal) from each primary document. Next it pulls out each reference and creates a first pass identification number. Although identification numbers are changed upon matching, the first pass identification number is retained so that information about original citation source is not lost.

Among the references, journal articles offer the most consistent citation format. Journal articles are identified by author, year, and page numbers as listed at the end of the citation. Because references are not consistent about which symbols separate values, it is not possible to directly match on title. Commas, periods, and semi–colons may represent separation between fields such as author, year, or title or they may separate multiple author names. Without this type of consistency, it is not possible for Synapse to directly identify what information should be pulled out as the title.

For non-journals, the situation is even more complex. Reports may or may not have authors listed. Years may appear anywhere in the citation including in the middle of the title. To deal with this complexity, non-journals are separated out from journal articles. These secondary citations are placed in a non-journal bin to be matched to one another through a blast technique. The blast technique takes sections of each reference and compares them with sections taken from every other reference. Synapse takes five sections, each twenty characters in length, to compare with clips from other references. When references are matched at a minimum threshold level of 80% consistency, they are considered to be a true match. After the matching process, all articles are assigned a new unique identification number and the new dataset is structured for export to Pajek. Pajek .net files are structured such that all unique documents are vertices and citations between documents are edges.

In Pajek the citation data is visualized using a separate components, Kamada-Kawai

(1989), energy layout. Next an all degree distribution is run to display the frequency of connections across citations in the data sample. Once visualized, clusters of citations are identifiable. By identifying each citation cluster and connection, significant citations with multiple connections can be discerned. Frequencies are run on the identifiable network within the citation data.

Results

The Scopus database was chosen for data sampling over alternative databases as it returned the maximum number of primary citations. As shown in Table 3.1 Scopus returned 552,306 documents on sanitation topics published from 2000 to 20013. Web of Science returned 204,319 while JSTOR returned only 42,298. Not shown in the table, Google Scholar retrieved 581,000 results. Google Scholar was not able to retrieve the entire list of keywords for user incorporation so it was not pursued further as a potential data source. Scopus retrieved 204,204 articles on user incorporation, Web of Science returned 53,882, and JSTOR returned 41,337. When sanitation and user incorporation were combined into a single search, in Scopus the dataset narrowed to 9,481 documents while in Web of Science the same search reduced to 771 documents. The intersection of topical areas produced a much larger sample from Scopus so Web of Science was ruled out as a data source. JSTOR was not able to process the combination of the sanitation and user searches so it was also eliminated. Adding the developing world to our search reduced the sample pool to 2,701 articles and engineering restricted the sample to 1,847 records. Eliminating articles that referenced hospitals reduced the final sample to 1,749 articles.

When disaggregated into primary and secondary documents, the initial data pool increased to more than 117,000 records. These 117,000 records represent all instances that the primary and secondary references appear in the sample, where after matching the true final sample size is reduced. From the matched references we took a sample of 3,637 records on which we performed a network analysis. In Pajek, we were able to determine that the article with the highest number of connections, or degrees, had 204 connections. The average number of degrees was 2 with a standard deviation of 8.6. The median number of degrees was 1. The degree distribution for all records in the sample is shown in Figure 3.7.

In Figure 3.8 the data are represented through the Kamada-Kawai Energy layout. Two features are discernable in this layout. The results show a single cohesive network and multiple isolated references (see Figure 3.9). The isolated citations are single articles with all of their references and are therefore not of interest. They will be eliminated from display with further development of Synapse. Figure 3.10 shows the network of interest stretched to more easily view individual records. Considering only records that bridged between other records, 52 individual records are identifiable as nodes that are all linked through the single large network. Citation information (first author, year, and title) is shown in Table 3.2 for each of the 52 nodal records. The modal number of degrees is 2 while the average number of degrees is 2.5, with a standard deviation of 1.6.

Figure 3.11 shows that most records provide connections between other citations but four records had five or more connections. The unique identification numbers along with their connections and degree levels for these four records is displayed in Table 3.3. The four highest degree nodes observed include ID 2127: Hope, R. 2013. Risks and Responses to Universal Drinking Water Security, ID 2544: Foster, T. 2013. Predictors of Sustainability for Community-Managed Handpumps in Sub-Saharan Africa, ID 2378: Habib, H. 2013. Jumpstarting Post-Conflict Strategic Water Resources Protection from a Changing Global Perspective, and ID 3051: Oberling, D.F. 2013. SEA Making Inroads in Land-Use Planning in Brazil: The Case of the Extreme South of Bahia with Forestry and Biofuels.

Discussion

The sample of 3,637 articles identifies four articles that provide key linkages between literatures. 2127: Hope, Robert. 2013. 'Risks and Responses to Universal Drinking Water Security' is a policy paper on information flows related to water governance under scarcity. The paper was authored by Hope, an environmental scientist with the School of Geography and the Environment at the University of Oxford, and was published in the *Philosophical Transactions of the Royal Society*.

2127 connects to 2544 directly through 2152, 2157, 2166, and 2189 and indirectly through 293 by 302 and 307. The articles 2152, 2157, 2189, and 2166 are each papers focused on rural water delivery in developing countries. 2152 is a follow-up study on handpump interventions that used a demand driven approach for implementation. 2157 is a World Bank report on the international Handpumps Project that was funded from 1981-1991. 2189 is a study of the use of handpumps in Africa to meet water security. The paper considers the disconnects between interventionists who task projects and users who are responsible for maintaining them. Finally, 2166 looks at cost recovery schemes for financing rural water projects. Together these papers represent a cluster of multidisciplinary studies (including environmental engineering, social sciences, environmental sciences, environmental policy, and international development) on the sustainability of Handpump interventions for water service delivery in rural, poor areas.

Article 293 examines how top-down interventions disable community capacity to sustain long-term intervention adoption. It considers how interventionists contribute to dysfunctional power structures in the local setting to disable implementation. 302 argues for sustained capacity building even with demand driven approaches to water interventions. Lastly, 307 states that there has been an over emphasis on participation such that participation has meant community management of systems; the authors argue that sustained operation requires outside management and oversight. Together these articles comprise a multidisciplinary debate, drawing from social science, environmental policy, and international development literatures, around the role of interventionists in sustaining interventions long-term and how to best support community capacity for water system management.

2544: Foster, Tim. 2013. ‘Predictors of Sustainability for Community-Managed Handpumps in Sub-Saharan Africa’ examines why water handpumps projects succeed or fail. Foster concludes that handpumps project failures were related to how remote a community is, lack of an acceptable and sustainable fee structure, and the age of system while successful projects had strong community organization and women’s participation in project oversight. The paper was authored by Tim Foster, an environmental scientist with the School of Geography and the Environment at the University of Oxford and was published in *Environmental Science and Technology*.

Hope (2013), an environmental scientist, draws from similar base literature as does Foster (2013), who is also an environmental scientist, to understand the challenges facing interventions to improve water accessibility under scarcity. 2127 and 2544 are characterized as drawing from the same discipline. Given the high degree of connectedness between the papers, the two papers share high network coherence and low diversity.

Article 2544 is connected to article 2378 via 2487, which is Elinor Ostrom’s (1990) *Governing the Commons*, which describes mechanisms that are used for governing common pool resources. Unlike Garret Hardin’s (1968) tragedy of the commons, Ostrom stated that community organizations could be used to manage common pool resources instead of relying solely on state intervention.

2378: Habib, Habibullah, A.J. Anceno, J. Fiddes, J. Beekma, M. Ilyuschenko, V. Nitivattanon, and O.V. Sippin. 2013. ‘Jumpstarting Post-Conflict Strategic Water Resources

Protection from a Changing Global Perspective' is a policy paper that looks for policy implications of strategic environmental assessment (SEA) of water management during conflict. SEA is a decision support tool used to incorporate environmental decision making into social and economic decision making. SEA is used in complement to project-based environmental impact assessments; SEA offers a pathway for translating EIAs into policy. The paper was authored by Habibullah Habib, an environmental engineer with Kabul University, and was published in the *Journal of Environmental Management*.

3051: Oberling, Daniel F., Emilio L. La Rovere, and Helena V. de Oliveira Silva. 2013. 'SEA Making Inroads in Land-Use Planning in Brazil: The Case of the Extreme South of Bahia with Forestry and Biofuels' looks at how SEA is used to make decisions about land use planning for forestry and biofuels production in Brazil. Oberling is a graduate student in environmental planning and the paper was published in *Land Use Policy.*

Article 2378 connects to article 3051 via articles 2506, 2480, 3089, 2394, and 2402. Articles 2506 and 2402 are resources with guidelines for carrying out strategic environmental assessments while 2480 and 2394 review how SEAs have been executed in different countries. Articles 2378, 2506, 2480, 2089, 2394, 2402, and 3051 all represent articles that use strategic environmental assessment in planning the management of environmental resources. Habib, as an environmental engineer, could be characterized as having a different disciplinary background as Oberling, who is an environmental policy scholar, and both could be described as having different disciplinary backgrounds than Hope and Foster who are environmental scientists. These distinctions are complicated, though, given that these scholars draw from multiple disciplinary backgrounds, blurring the boundaries between fields. This is indicative of the multidisciplinary nature of the area, but presents challenges in representing individual articles as being situated in any specific discipline domain.

Nonetheless, two distinct subclusters are apparent within the network: one considering grounded empirical research on the success or failure of handpumps and the other considering high level policy decisions related to environmental resource management. These two subclusters are linked through Ostrom's work on common pool resources. If diversity is defined by disciplinary background, the results of our network analysis on the sample data show low diversity. If diversity is defined by topical area (handpumps versus SEA), then more diversity is observed but we have characterized only two topical areas. The data show subclusters that have high network coherence but low coherence between subclusters.

Conclusion

Based on the subsample of 3,637 articles and references that were exported to Pajek, we were able to discern one cohesive citation network. Within this network, two principle clusters were identified. One cluster of articles pertained to the sustainability of handpump interventions while another focused on strategic environmental assessment. Both sets of literature drew from Ostrom's common pool resources argument in considering how to address the management of shared resources. Using Rafol (2010), we identify two subclusters within our network. Articles linking these subclusters lacked diversity but within the subclusters high network coherence was observed. Low network coherence was observed between the subclusters.

Interestingly, of the 3,637 records that were sampled from data explicitly targeting sanitation interventions in developing countries, no clusters of sanitation-specific interventions in developing contexts were identifiable. Our method specifically looks for linkages between articles. We did not find evidence to support the conclusion that there are high levels of network coherence within the sanitation literature. Because the 3,637 records represent only a small fraction of our data, the next step will be to run Synapse on the entire data set of over 117,000 records to see if clusters of sanitation articles are apparent.

Our method offers a straightforward approach to organizing citation data downloaded from Scopus for analysis in Pajek. As an open code script our method allows for evolution of the script and ongoing data cleaning and management, which the other proprietary software applications available do not permit. In spite of the fact that our preliminary literature review supported the availability of several methodologies for user inclusion into technology design and interventions, we find that the large body of literature on sanitation technology development for low-income settings largely does not examine the influence of household level users on sanitation technology design. Based on our preliminary network analysis, we find that this differs from interventions on improving water access. We believe a reason for this difference is because access to water in low-income settings is handled largely from a treatment frame, which relies on available technologies for treating contaminated water, while sanitation relies on a behavioral frame, which emphasizes individual choice in improving sanitation conditions. In the literature review we found that the literature on sanitation technology acceptability focuses on acceptability of reuse and not predominately on the user interface. The lack of attention to true coproduction of knowledge about sanitation technology points to an important gap in the literature and in intervention approaches.

One current limitation to our analysis is the newness of the Synapse program. As we continue to develop the program, we will be able to improve our match rate, develop automated techniques for categorizing our data into partitions, and will have more statistical tools available to us to examine our data. Beyond the sustainable sanitation literature, Synapse offers a valuable resource for surveying large bodies of literature for silences and opportunities for future research.

CHAPTER 4

'SYNAPSE'

Purpose

Synapse is a MATLAB script that processes citation data in ASCII format as downloaded from the Scopus database. The entire script for Synapse is presented in Appendix D. This script represents the PajekAll_minus_starburst.m file as of April 17, 2014, 12:45 pm. The data for Synapse are downloaded from Scopus as citations (primary documents) with each of their references (secondary documents) attached. Although consistent formatting is available for primary documents, secondary documents have inconsistent citation formats, which must be dealt with. First, Synapse creates a master list of all primary and secondary documents. Subsequently, the program uses a matching algorithm to attempt to identify duplicate records in the master list where multiple articles cite the same reference. In some cases articles cite other articles in the database, which then have their own citations. Synapse identifies all unique records, retains referring information to track which records cite which, and assigns a new unique identification number. The data are then structured for export to a Pajek .net file for network analysis using the Pajek software (Batagelj and Mrvar 2008). Pajek is not restricted by the size of a data file and is only limited by the processing capability of the computer on which it is run.

Overview

Creating a Master List

First, the script imports the data from an ASCII text file. Records downloaded from Scopus are ordered such that the first line of the record has the author information, the second has the title, and the third has other referencing information. For a journal article this includes year, publication, volume, issue, and page numbers. The references are then identified by the word "REFERENCES:". References are separated from one another by semi-colons and a carriage return. Two carriage returns separate primary records. Synapse collects primary document citation information and strips the word "References:" from each record. Identification numbers are created for each primary article. Along with the reference identification number from the primary article, a secondary level identification number is attached to each secondary document. A timer is set to count the amount of time the program takes to create the list of articles and references. By this stage, a master list of all instances of primary and secondary documents is created. From a sample data file of 1,702 articles, the master file at this stage had a total of 117,761 documents. Many of the documents at this point are duplicates so the next step is matching.

Matching

Matching of documents occurs in two parts. The simpler of the two steps is the identification and matching of journal articles. Journal articles have a semi-consistent citation format that begins with first author last name and ends with the page numbers of the article in a journal. The page numbers occur at the end of the citation and begin with 'pp.' or 'p.'. Documents ending in 'pp.' or 'p.' are identified as journal articles and are separated into a journal bin whereas documents that do not end in 'pp.' or 'p.' are moved to a non-journal bin.

Within the journal bin, articles are matched first based upon first author and page numbers and then a blast selection from the citations. Blasting selects a segment of characters take from one source and matches with another segment of characters taken from a second source. If a minimum level of consistency is met across a minimum number of blast segments, the first and second sources are considered to be a match. This technique is similar to the technique used to identify sections of genetic code using a PCR analysis. During the match process a unique identification number is created for each matched document. The identification number reflects the first instance of the reference with all subsequent instances renamed with the identification number from the first instance.

In the non-journal bin page numbers are not available to assist in matching. Author names may also not be available if the publication is a report or if author names simply are missing. As such, only the blast technique is available to identify matches. The technique used in the current version of the code is to take five blast segments of length twenty characters from each record. If three of the five segments have at least 80% consistency the record is considered to be a match. The program calculates the total number of matches after all processing.

Output to Pajek

The Pajek data file is a basic ASCII text file with two sections: vertices and edges. To output the data to Pajek, new unique identification numbers must be created. For n records, the identification numbers must be sequential numbered from 1 to n. For use in Pajek, each record represents a vertex while each citation between records represents an edge. Pajek does allow for directionality through the use of arcs but to simplify visualization non-directional edges are used instead. Vertices are represented through the command *vertices, the total number of records included as vertices, a line break, followed by a list of records (one record per line). A label can follow the vertex if the label is enclosed in quotation marks. Edges are represented through the command *edges, a line break, followed by the identification number for a document, a space, the identification number for a cited document, and a weight value. Weights affect the thickness of the lines representing connections. For our purposes all weights are assigned a value of 1. Weights could be given different values if we wanted to reflect some other aspect about the connection between the documents. For simplicity, we keep that value at 1. The final text file is renamed .net to import directly into Pajek. An example of the structure of the .net file for 3,637 records is as follows:

```
*Vertices     3637
1     "a1-"
2     "a1-r1"
3     "a1-r2"
4     "a1-r3"
5     "a1-r4"
.
.
.
*Edges
1     2     1
1     3     1
22     26     1
22     27     1
37     56     1
37     57     1
.
.
.
```

Challenges and Improvements

Data downloaded from Scopus presents a number of challenges for identification and matching. Documents may have author names or publications fully written out or abbreviated. Author names may or may not include middle names. Multiple instances of values that appear to be years with the format (####) may occur throughout the record. Author names may have non-English character scripts, which become corrupted when citations are downloaded. Publication titles may be in different languages and may also become corrupted. As well, there are simply errors in how the data are intended to be structured versus how they are actually structured. The advantage of Synapse is that we have the flexibility to address each of the challenges. The challenge is in doing so. Some of the challenges we have already identified with possible approaches to addressing them are described as follows.

Errors occur in the datafile downloaded from Scopus. In some instances, multiple references were attached to each other in the same line. Currently the code deletes these records.

An improvement on this is to create a user interface wherein the code requires user information as to how to handle these records. The user could tell Synapse to delete all of these inconsistencies or the user could be able to click inside the reference to tell Synapse where to separate the references.

Using page numbers for matching presents a challenge when page numbers are abbreviated. Some references may list page numbers fully (e.g., p3345-3367 or p3397-3415) while others may shorten them (e.g., p3345-67 or p3397-15). This inconsistency should be addressed.

Duplicate page numbers may exist for a single author. While pages numbers are likely random throughout journal publications, some page numbers may have a higher probability of occurrence. Specifically, authors may have multiple publications at the beginning of a journal, which could begin with page 1. If so, the author's last name and page numbers would not uniquely identify a record. This problem is compounded if the first author has a common last name. For instance, 'Smith ________ p1-20' could be common among citations.

It is possible that some journal articles are moved to the non-journal bin where they would not have the opportunity to match back to the journal bin. To improve matching, the journal and non-journal bins could be recombined at the end to conduct a second round of blast matching to identify more matches. Because the blast matching is the largest time sink for the program, this could be an optional step if insufficient matches are initially identified.

As shown in Figure 4.1, the choice of number of segments and segment length may be less than optimal. A sample of 1,250 non-journal citations that were run through the blast technique produced a maximum of 65 matches but at least half of these matches were incorrect. Another quarter of the matches were marginal matches which were not identical but acceptable. The marginal matches represent a trade-off because ideally the code should be able to have flexibility in its matching to allow for inconsistent formatting (e.g., fully written out journal titles versus abbreviated journal titles). However, some marginal matches may genuinely be different publications such as similar author names or documents produced in editions that have been published across different years. From Figure 4.1, it appears that based on the sample of 1,250 records the optimal technique is to take 30 segments and allow for 70% consistency in matching. Another way of varying matching could be to take more frequent but shorter segments and increase the degree of consistency required.

In creating the data to export to Pajek, it may be helpful to retain directionality through the use of arcs instead of edges. Pajek has the capability to convert arcs to edges so should the results become too cluttered upon visualization they can be converted at a later time. By using arcs, more information is retained and is available for Pajek to use in analysis.

To create labels for Pajek, it would be helpful to display each record with its Pajek identification number and the year of publication. This is particularly valuable if edges are used instead of arcs. Using the identification number and the publication year keeps labels concise but provides helpful information about directionality of citations.

Future Directions

To maximize Pajek's network analysis capabilities, an automated or semi-automated method for creating partitions and/or vectors should be created. Pajek considers partitions to be categorical clustering of records. Records may be partitioned according to disciplinary field or topical area. It is possible that partitions could be created by drawing upon keywords from documents, but a challenge to overcome then is how to identify keywords for records that only appear as references. Through the use of partitions, the diversity of networks can be more easily shown. Vectors are values that quantify the magnitude of influence a record has. The number of times a record has been cited or the H-Index for an author could be different ways of assigning vectors to records.

A key improvement on Synapse would be the addition of a user interface to work with Synapse in maintaining quality control in the data. As described previously, an interface would be helpful in parsing out separate references if they have been inadvertently tied together. Another benefit of a user interface would be to allow the user to reconcile marginal matches. This is useful for handling marginal matches of references that have different years or abbreviated author and journal names.

In general Synapse offers a valuable tool for simplifying vast quantities of literature. While sanitation is a broad interdisciplinary topic, we found that through focusing on the discrete area we were interested in, in fact interdisciplinarity disappeared. Synapse is a resource that combined with Pajek can be of broad use in managing academic literature, the volume of which can be daunting. This method is helpful particularly in surveying large quantities of publications to identify targeted areas of research that are underdeveloped.

CHAPTER 5

CONCLUSION

This thesis set out to identify how engineers incorporate users into sanitation technology design. To develop an understanding of approaches to user inclusion in development projects for low-income communities, the thesis begins with a historical review of different frames for approaching international sustainable development projects. Literature on sustainable sanitation derives from an international health focus on improving well-being and reducing poverty dating back to the late 1940s with the WHO initiatives on environmental sanitation. The WHO worked with international aid organizations to promote economic development in poor countries in order to improve health outcomes and reduce the transmission of disease.

International health based efforts on reducing poor sanitation conditions coalesced with sustainable development initiatives, first popularized by the Brundtland Commission. Sustainable development initiatives emphasized improving efficiency and reducing waste in technological development but not reducing either production or consumption. Sustainable development policies emphasize continued production without sacrificing the ability of future generations to do the same. Sustainable development and environmental sanitation explicitly came together in 2000 with the Bellagio Principles for Sustainable Sanitation and in 2002 the goal to reduce the proportion of the world's population without basic sanitation by half was added to the Millennium Development Goals.

Historically, three primary themes have emerged in addressing sustainability of interventions for improving the living conditions of poor populations in developing countries. These three themes include the appropriate technologies movement, the shift from hardware to software, and the emphasis on user participation in intervention planning and execution.

Appropriate technologies emphasized identifying technologies that fit for local contexts but the approach was criticized for being top down and implying that developing countries are deserving of lower quality technologies. The shift from hardware to software emphasized a movement away from identifying technological solutions to addressing intangible factors that influence the success of interventions, such as community capacity, finances, trust, and the need for behavioral changes. Although behavioral change is required with any intervention, this approach has been criticized for over-emphasizing behavioral change and education while downplaying the significance of power inequalities that lead to conditions of extreme poverty. Finally, the participation frame emphasizes community and user participation to ensure acceptability and adoption but participation has many interpretations and often participation is reduced to manipulative and consultative relationships with target populations.

Our principle interest is in identifying how engineers specifically situate themselves within intervention projects and how they go about considering the role of users in sanitation technology development. We identified four broad ways in which engineers can include users into technology planning: appropriate technologies, user-centered design, multiple criteria decision analysis, and participatory action research. All of these methods except participatory action research rely on a top-down model of intervention where engineers remain in control of process planning. Participatory action research, although it allows for redistribution of power and enhanced community capacity, is difficult to execute, requires long-term community investment, and poses a number of professional challenges for engineers to adopt. Of the methods identified, the Adaptive Decision Making Process seems the most likely method that engineers will adopt if they are interested in investing in sustainable sanitation interventions. This method remains hierarchical but when invested in deeply, offers an opportunity for collaborative exchange between engineers and target communities.

When examining the broad body of literature on sanitation in developing countries, we could identify no area of scholarship that was actively working in promoting any of the user incorporation methods in sanitation innovation. The connections that we did identify in our network analysis had high network coherence but low diversity. Because sanitation did not appear at all in our network analysis, we conclude that the literature on user incorporation in sanitation innovation has low network coherence. Analysis on a larger dataset will inform upon this preliminary conclusion. This project finds that more peer-reviewed literature on how engineers participate with target populations in interventions is necessary. While from our initial analyses it appears that the answer to our research question is that in fact engineers do not engage users in sanitation technology innovation, it may also be that insufficient studies on this engagement are published in peer-reviewed literature.

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APPENDIX A

TABLES

Table 1.1. Progress Towards Millennium Development Goals for Water and Sanitation (UNDP 2006, cited in Jiménez and Pérez-Foguet 2010)

Parameters	Water supply	Sanitation
World coverage	87%	62%
World rural coverage	78%	45%
World urban coverage	96%	79%
Estimated year for attainment of MDGs (world)	2016	2022
Estimated year for attainment of MDGs in Sub-Saharan Africa	2040	2076

Table 3.1. Database Queries for Sanitation and User Inclusion for Documents Published From 2000 to 2013

	Scopus[1]	Web of Science[2]	Jstor[3]
S: Sanitation	552,306	204,319	42,298
U: Users	204,204	53,882	41,337
Sanitation + Users	9,481	771	§
D: Developing Countries	392,688	124,188	NA
S + U + Developing Countries	2,701	114	NA
E: Engineering	6,642,394	1,044,711	NA
S + U + D + Engineering	1,847	36	NA
S + U + D + E - Hospital	1,749	36	NA

Time frame 2000-2013
1 Scopus search by all fields in articles, articles in press, and books
2 Web of Science search title or topic in all document types
3 Jstor search by full text in articles and books
§ Jstor could not process the query for sanitation + users as it was too long

Table 3.2. Node ID Numbers with First Author, Year, and Title

ID	Citation
67	Starkl, M. 2013. A planning-oriented sustainability assessment framework for peri-urban water management in developing countries.
82	Katukiza, A.Y. 2010. Selection of sustainable sanitation technologies for urban slums - a case of Bwaise III in Kampala, Uganda.
95	Peter-Varbanets, 2009. Decentralized systems for potable water and the potential of membrane technology.
293	Mugumya, F. 2013. Governance dynamics disabling the sustainability of community-managed point-water facilities in rural Uganda.
302	Lockwood, H. 2011. Supporting Rural Water Supply: Moving Towards a Service Delivery Approach.
307	Harvey, P.A. 2007. Community-managed water supplies in Africa: Sustainable or dispensable?
318	Tsinda, A. 2013. Challenges to achieving sustainable sanitation in informal settlements of Kigali, Rwanda.
320	Oosterveer, P. 2010. Meeting Social Challenges in Developing Sustainable Environmental Infrastructures in East African Cities.
329	Scheinberg, A. 2011. Assessing urban recycling in low-and middle-income countries: Building on modernised mixtures.
337	Moe, C.L. 2006. Global challenges in water, sanitation and health.
515	Furlong, C. 2013. Returning knowledge to the community: An innovative approach to sharing knowledge about drinking water practices in a peri-urban community.
522	Fewtrell, L., 2005. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis.
531	Prokopy, L.S. 2005. The relationship between participation and project outcomes: Evidence from rural water supply projects in India.
540	Okem, A.E. 2013. Assessing perceptions and willingness to use urine in agriculture: A case study from rural areas of eThekwini municipality, South Africa.
561	Oyoo, R. 2013. The determination of an optimal waste management scenario for Kampala, Uganda.
574	Garfi, M., 2011. Multi-criteria analysis for improving strategic environmental assessment of water programmes. A case study in semi-arid region of Brazil.
591	Scheinberg, A., 2010. Multiple modernities: Transitional Bulgaria and the ecological modernisation of solid waste management.
600	Vollmer, D., 2013. Rivers as municipal infrastructure: Demand for environmental services in informal settlements along an Indonesian river.
601	Adger, W.N., 2006. Vulnerability.

Table 3.2. Node ID Numbers with First Author, Year, and Title (continued)

ID	Citation
661	Seto, K.C. 2011. Exploring the dynamics of migration to mega-delta cities in Asia and Africa: contemporary drivers and future scenarios.
668	Turner, B.L. 2003. A framework for vulnerability analysis in sustainability science.
858	Sadr, S.M.K. 2013. Appraisal of membrane processes for technology selection in centralized wastewater reuse scenarios.
864	Shannon, M.A. 2008. Science and technology for water purification in the coming decades.
875	Khan, S. 2009. Water management and crop production for food security in China: A review.
965	Enéas da Silva, F.O. 2013. Developing sustainable and replicable water supply systems in rural communities in Brazil.
970	Carter, R.C. 1999. The impact and sustainability of community water supply and sanitation programmes in developing countries.
979	Kleemeier, E., 2000. The impact of participation on sustainability: An analysis of the Malawi Rural Piped Scheme program.
982	Montgomery, M.A., 2009. Increasing functional sustainability of water and sanitation supplies in rural Sub-Saharan Africa.
1058	Amoo, O.M. 2013. Renewable municipal solid waste pathways for energy generation and sustainable development in the Nigerian context.
1084	Imam, A. 2008. Solid waste management in Abuja, Nigeria.
1111	Akter, S. 2013. The poverty-vulnerability-resilience nexus: Evidence from Bangladesh.
1154	Jiang, Y. 2013. China's water management – challenges and solutions.
1722	Bluemling, B. 2013. The social organization of agricultural biogas production and use.
2064	Uguru, O.P. 2013. Water scarcity and health in arid regions: A comparative study of Nigeria and Spain.
2098	Sagheer Aslam, M. 2013. Environmental sustainability of rural community-based drinking water systems in developing countries.
2127	Hope, R. 2013. Risks and responses to universal drinking water security.
2152	Whittington, D. 2009. How well is the demand-driven, community management model for rural water supply systems doing?
2157	Arlosoroff, S. 1987. Community Water Supply: The Handpump Option.
2159	Briscoe, J. 1988. Water for Rural Communities: Helping People Help Themselves.

Table 3.2. Node ID Numbers with First Author, Year, and Title (continued)

ID	Citation
2166	Harvey, P. 2007. Cost determination and sustainable financing for rural water services in sub-Saharan Africa.
2189	Hope, R.A. 2012. Reducing risks to rural water security in Africa.
2378	Habib, H. 2013. Jumpstarting post-conflict strategic water resources protection from a changing global perspective.
2394	Chaker, A. 2006. A review of strategic environmental assessment in 12 selected countries.
2402	Dalal-Clayton, B. 2005. Strategic Environmental Assessment: A Sourcebook and Reference Guide to International Experience.
2480	Noble, B.F. 2009. Promise and dismay: the state of strategic environmental assessment systems and practices in Canada.
2487	Ostrom, E. 1990. Governing the Commons: the Evolution of Institutions for Collective Action.
2506	Therivel, R. 2004. Strategic Environmental Assessment in Action.
2544	Foster, T. 2013. Predictors of sustainability for community-managed handpumps in sub-Saharan Africa.
2783	Sima, L.C. 2013. Modeling risk categories to predict the longitudinal prevalence of childhood diarrhea in Indonesia.
2947	Baraki, Y.A. 2013. Technology transfer of hand pumps in rural communities of Swaziland.
3051	Oberling, D.F. 2013. SEA making inroads in land-use planning in Brazil: The case of the Extreme South of Bahia with forestry and biofuels.
3089	Sadler, B. 1996. Environmental Assessment in a Changing World: Evaluating Practice to Improve Performance.

Table 3.3. Nodes and Connections within the Citation Network

Nodes	Connections										Degree
2783	522										1
522	2783	515									2
515	522	531									2
531	515	2127									2
2127	531	293	2152	2157	2159	2189	2166	979			8
293	2127	302	307								3
302	293	2544									2
307	293	2544									2
2152	2127	2544									2
2157	2127	2544									2
2159	2127	2544									2
2189	2127	2544									2
2166	2127	2544									2
2544	970	982	302	307	2152	2157	2159	2189	2166	2487	10
2487	2544	2378									2
2378	2487	2506	2480	3089	2394	2402					6
2506	2378	3051									2
2480	2378	3051									2
3089	2378	3051									2
2394	2378	3051									2
2402	2378	3051									2
3051	2506	2480	3089	2394	2402						5
970	2544	965									2
982	2544	965	2947								3
2947	982										1
965	979	970	982	337							4
979	2127	965									2
337	965	540	2064	318							4
540	337										1
2064	337	1084	864								3
1084	2064	1058									2
1058	1084										1
864	2064	858									2
858	864	82	875								3
82	858	67									2
875	858	1154									2
1154	875	661									2
661	1154	600									2
600	661	601	668								3
601	600	1111									2
668	600	1111									2
1111	601	668									2
318	337	329	320								3
329	318	561									2
320	318	1722									2
561	329	591	574								3
1722	591	320									2
591	1722	561									2
574	561	2098									2
2098	574	95									2
95	2098	67									2
67	95	82									2

APPENDIX B

FIGURES

Figure 2.1. The Tanzanian *Choo Bora* and the Indonesian *Lik Telek* Behavior Change Campaigns Against Open Defecation (Perez et al. 2012, p8)

Behavior change messages were country specific and, as a result, messages varied widely. Communication materials developed in Tanzania (left) featured a positive image and message to tap aspirational values. *Choo Bora Chawezekana! Tumeamua Maendeleo Hadi Chooni* roughly translates to "A Good Toilet is Possible! We've Taken Development All the Way to the Toilet!" Communication materials developed in Indonesia (right) featured *Lik Telek* ("Uncle Shit") to remind people that open defecation was socially irresponsible and that people who defecated in the open would feel shame and become a subject for gossip.

Figure 2.2. Factors Affecting Success of Wastewater Reuse (Almasri and McNeill 2009, p432)

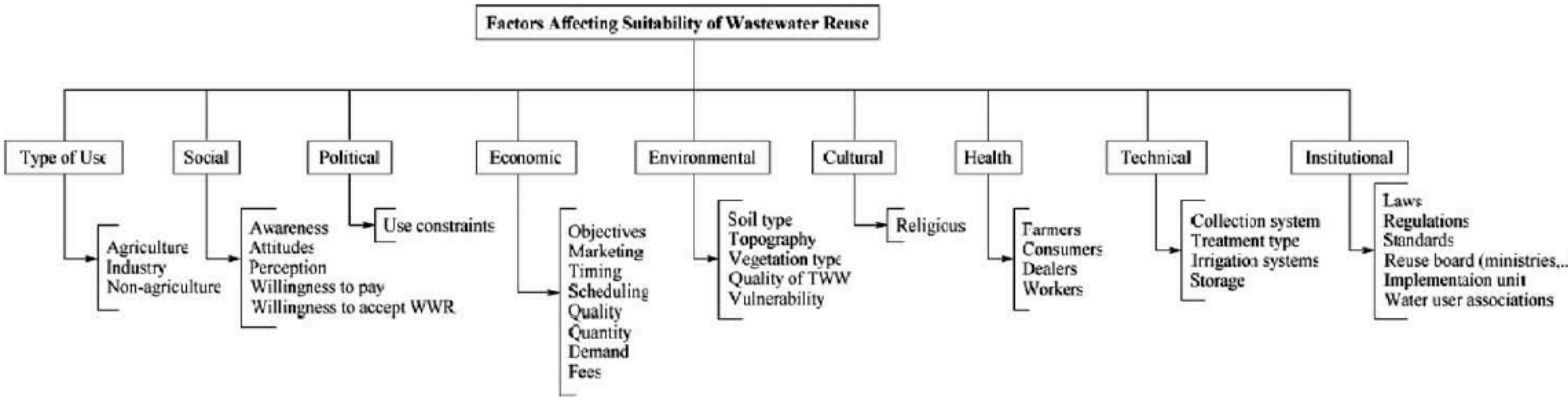


Figure 2.3. Schematic of Urine-Diversion Dry Latrine (Duncker et al. 2007, p10)

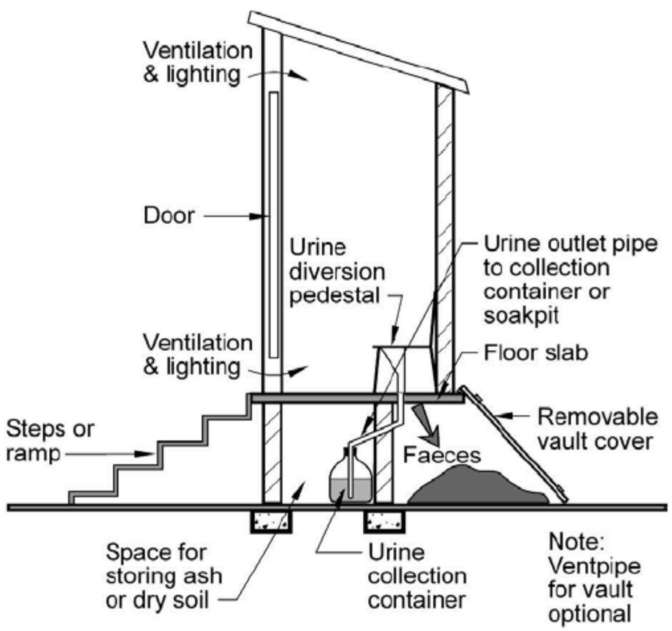


Figure 2.4. Degree of Participation by Participants in Research from Participant to Partner (Balazs and Morello-Frosch 2013, p10)

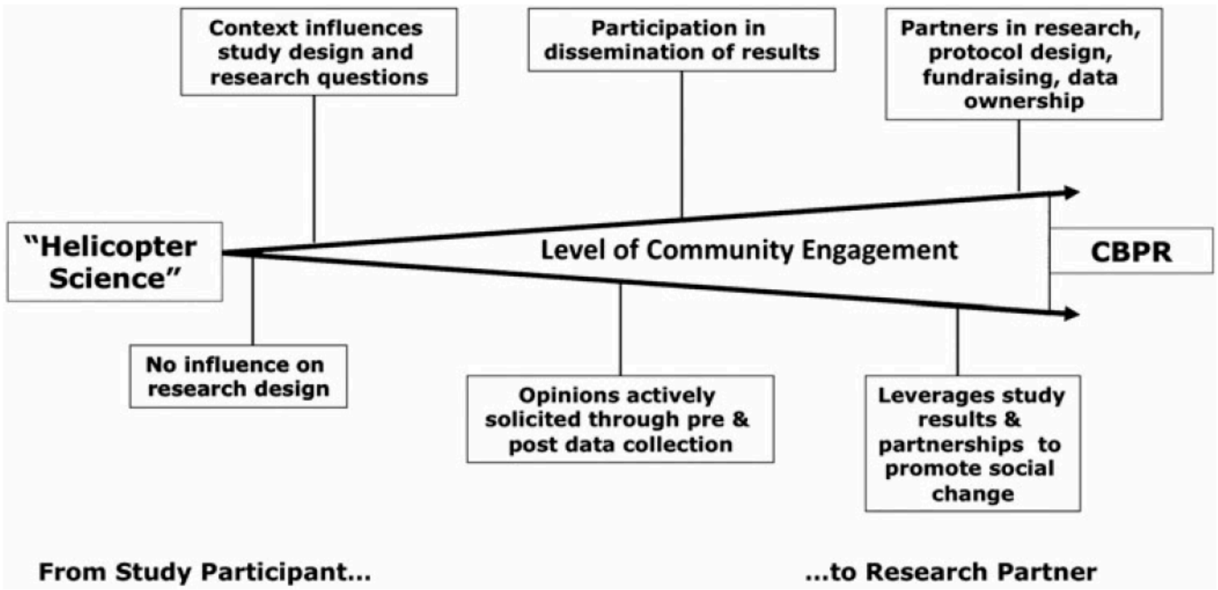


Figure 3.1. Theoretical Distribution of Network Coherence and Diversity (Rafols and Meyer 2010, p270)

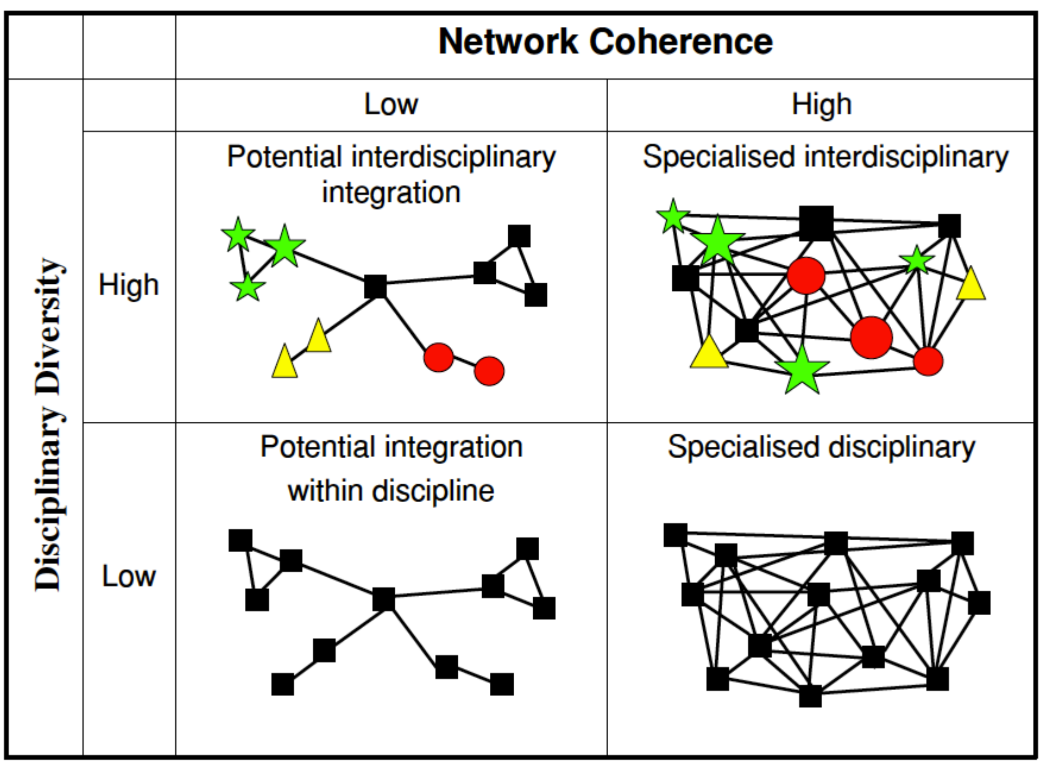


Figure 3.2. A Model of Diffusion for Appropriate Technologies (Ramani et al. 2012, p683)

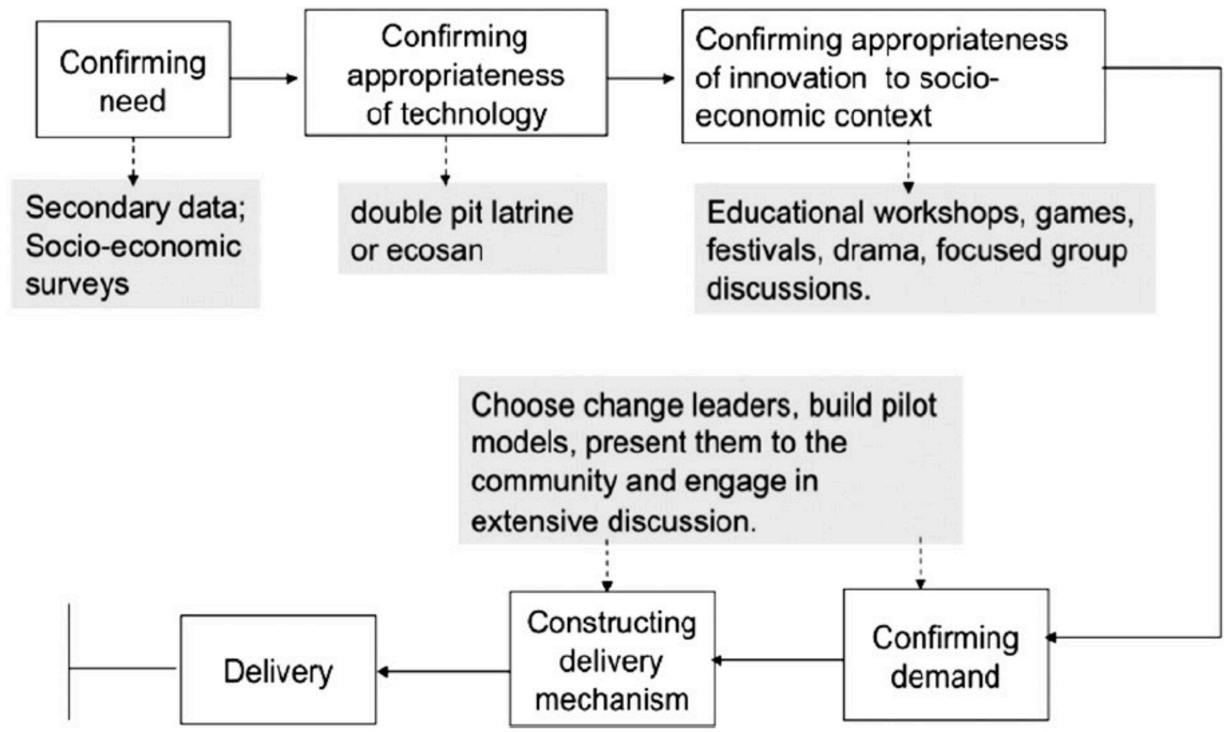


Figure 3.3. The Human Centered Design Process, ISO-13407 (ISO 1999, quoted in Lindström and Malmsten 2008)

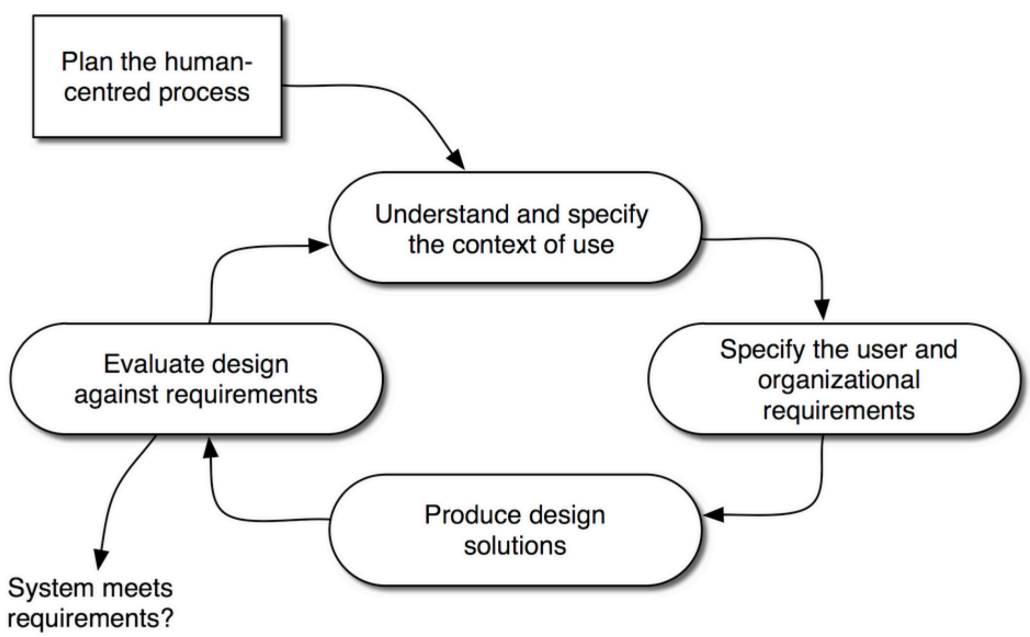


Figure 3.4. The Adaptive Decision Making Process (Lal et al. 2001)

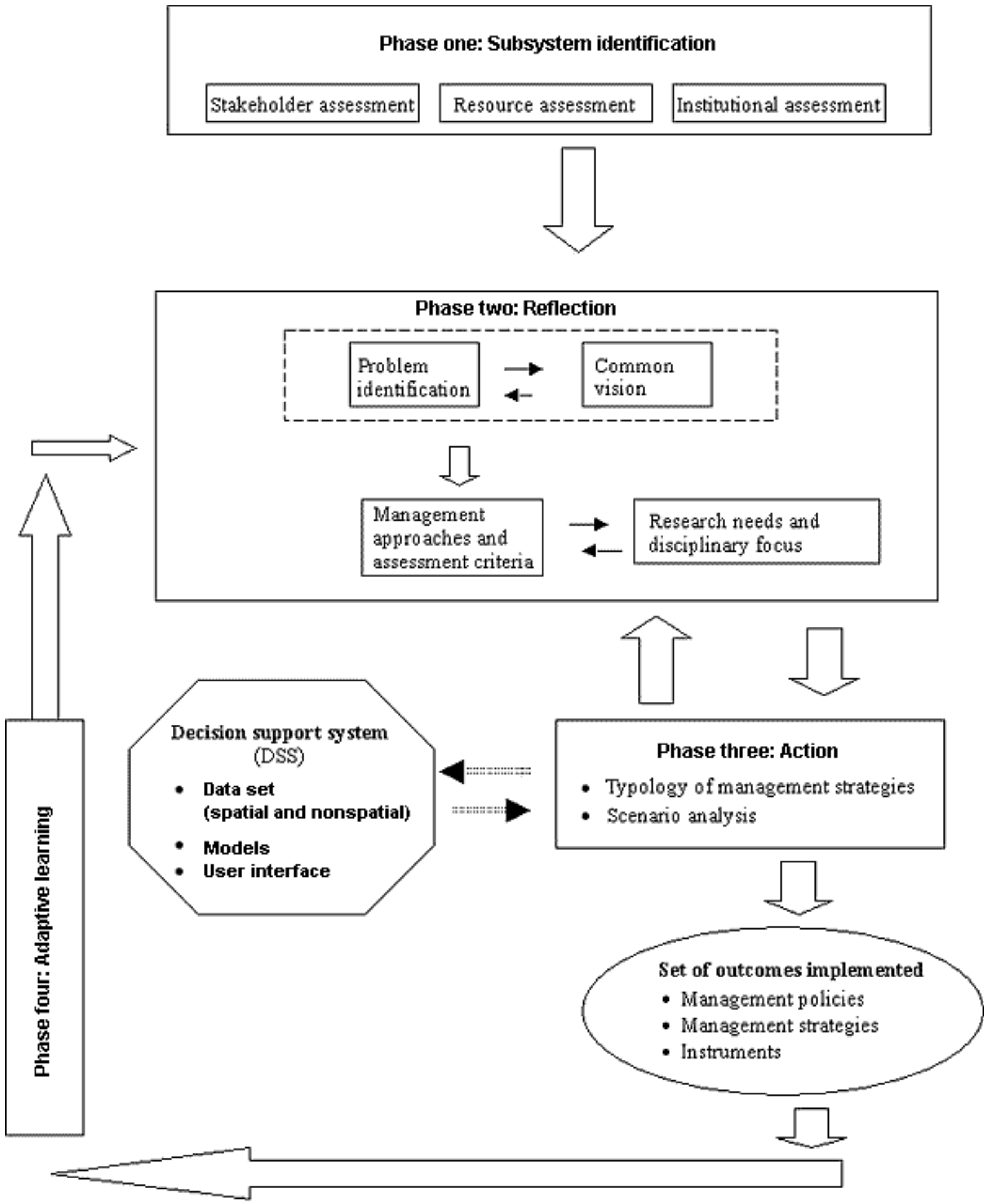


Figure 3.5. Schematic of a Multiple Attribute Decision Making Framework for Determining Suitable Wastewater Treatment Technology (Kalbar 2012, p298)

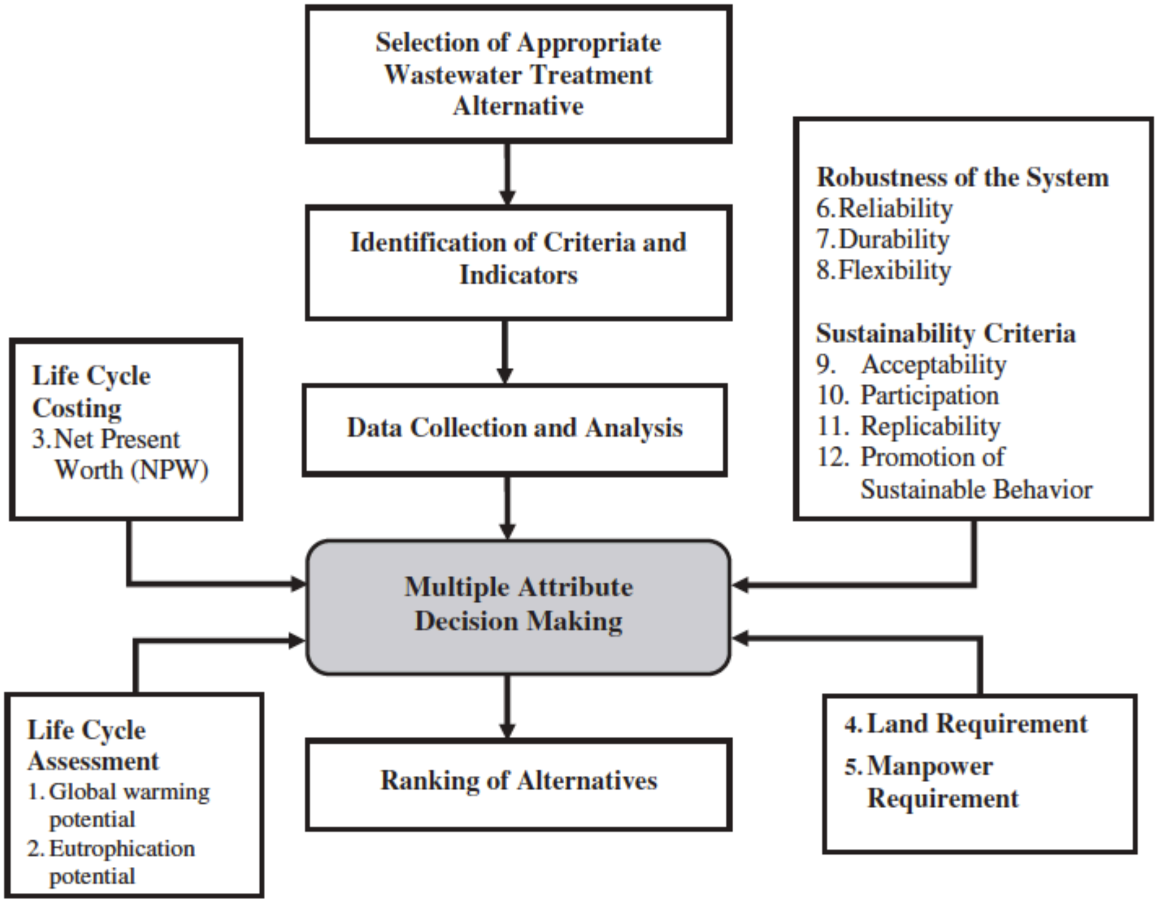


Figure 3.6. The Household-Centered Environmental Sanitation Approach (Eawag 2005, p23)

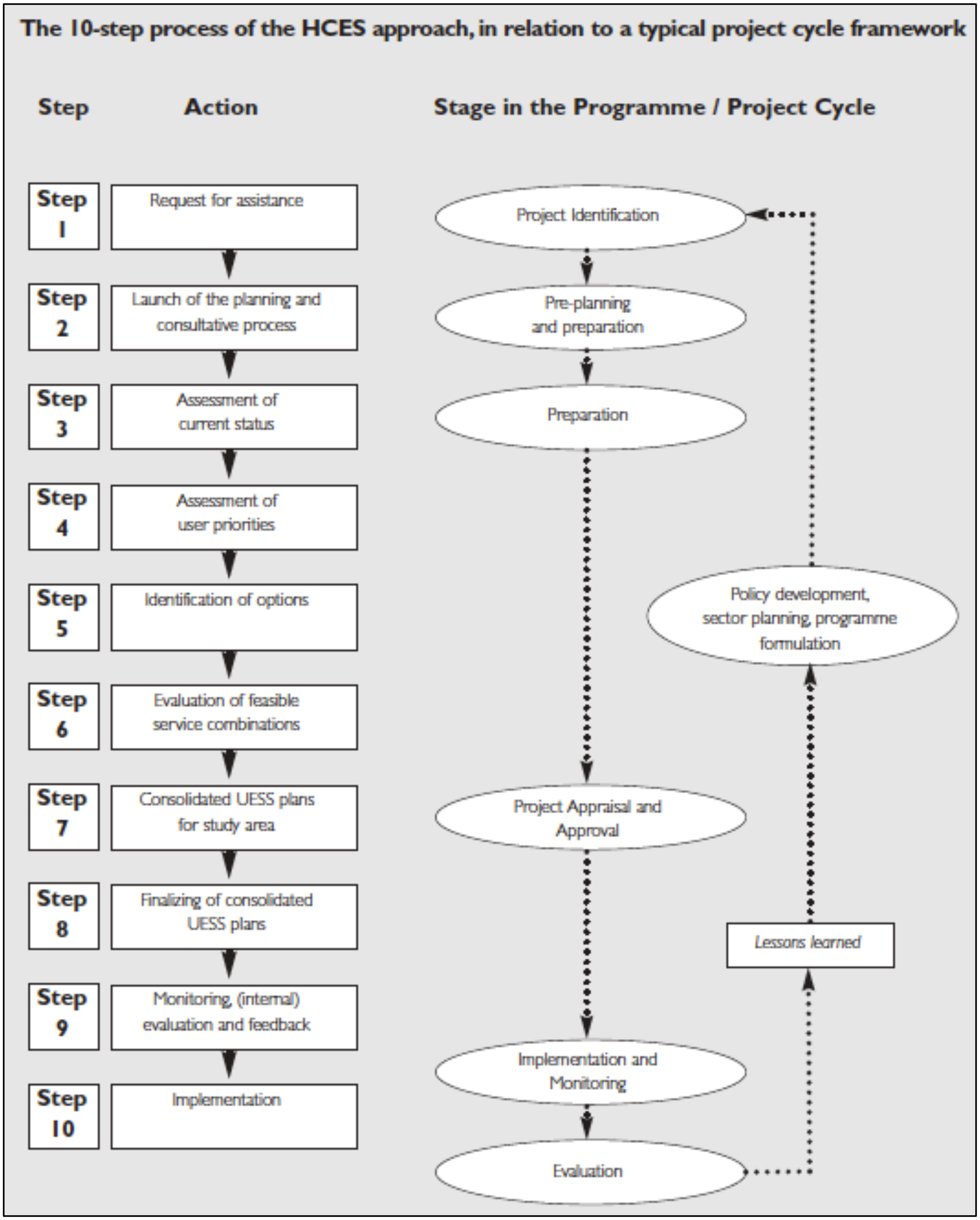


Figure 3.7. All-Degree Distribution of This Study's 3637 Sample Records (code to produce the plot from Batagelj 2009)

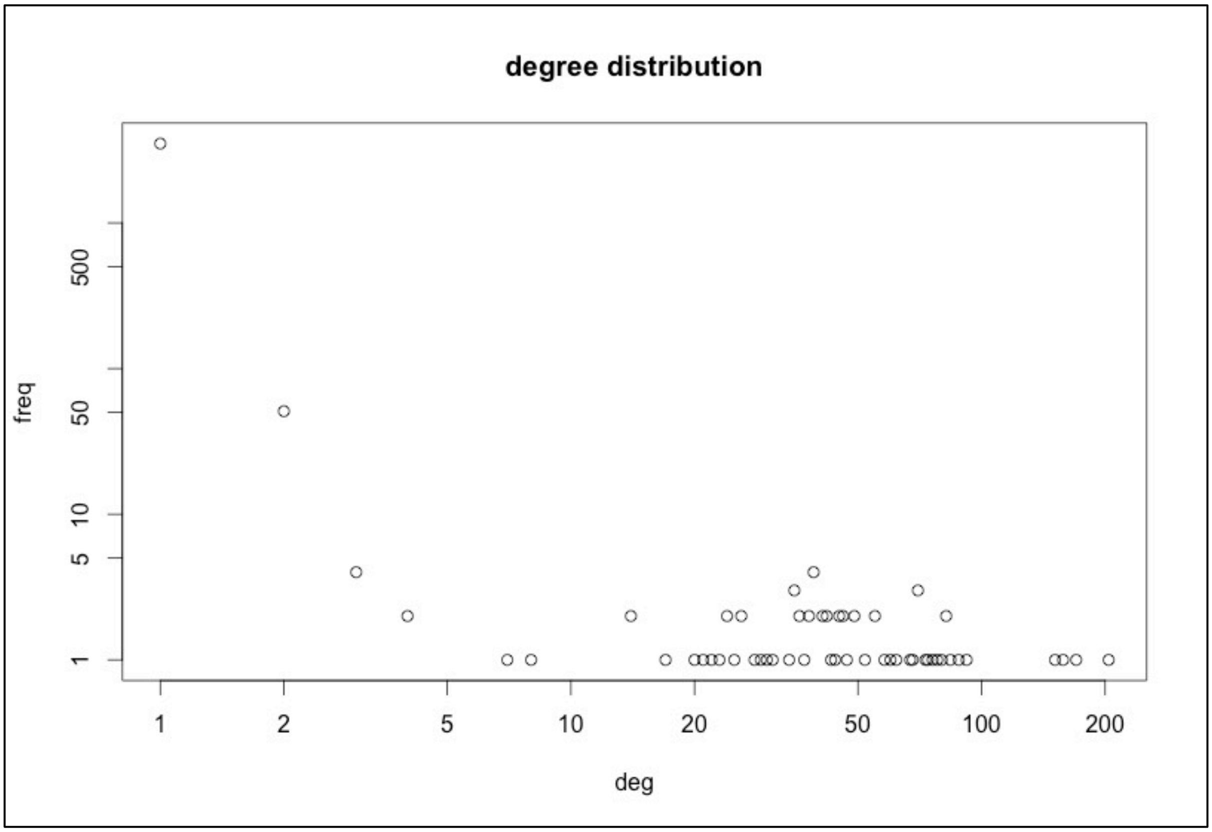


Figure 3.8. Network Analysis using Pajek (Batagelj and Mrvar 2008) of This Study's 3637 Sample Records

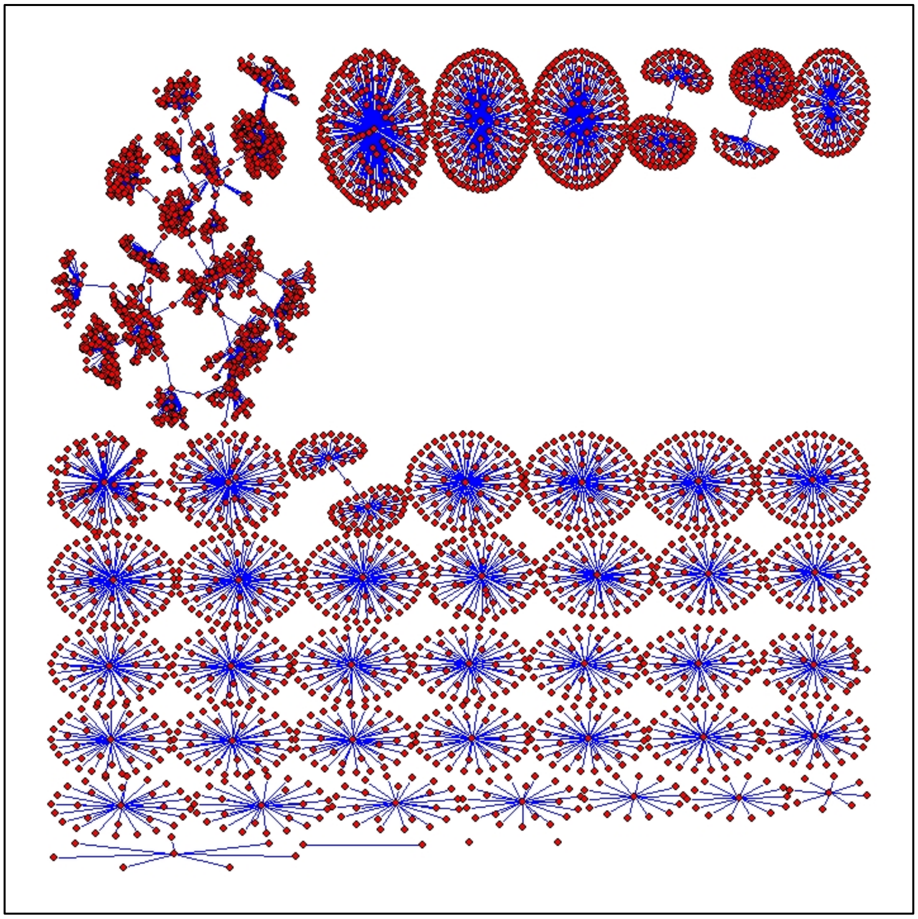


Figure 3.9. Isolated Citations with only References and Few or No Connections

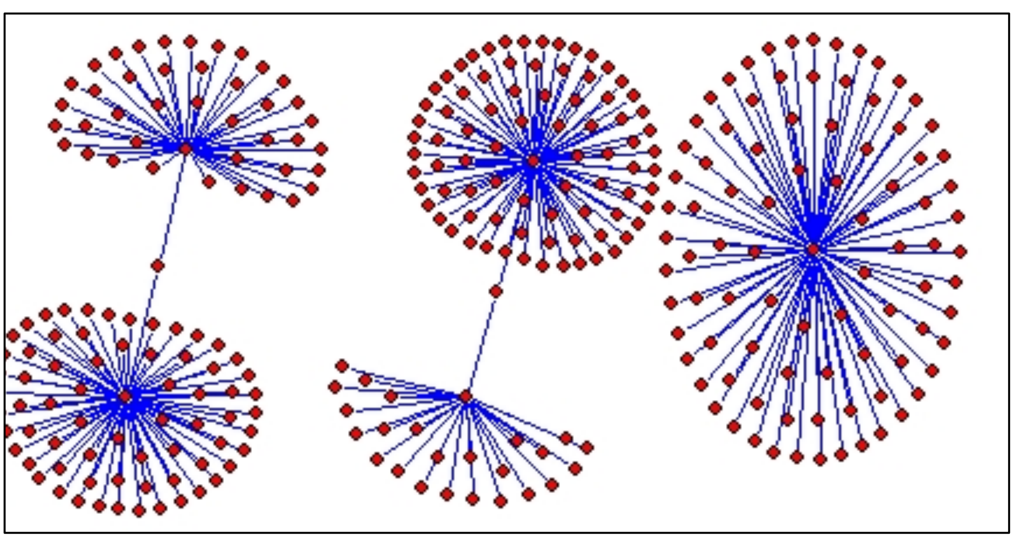


Figure 3.10. Key Nodes with Bridging Connections

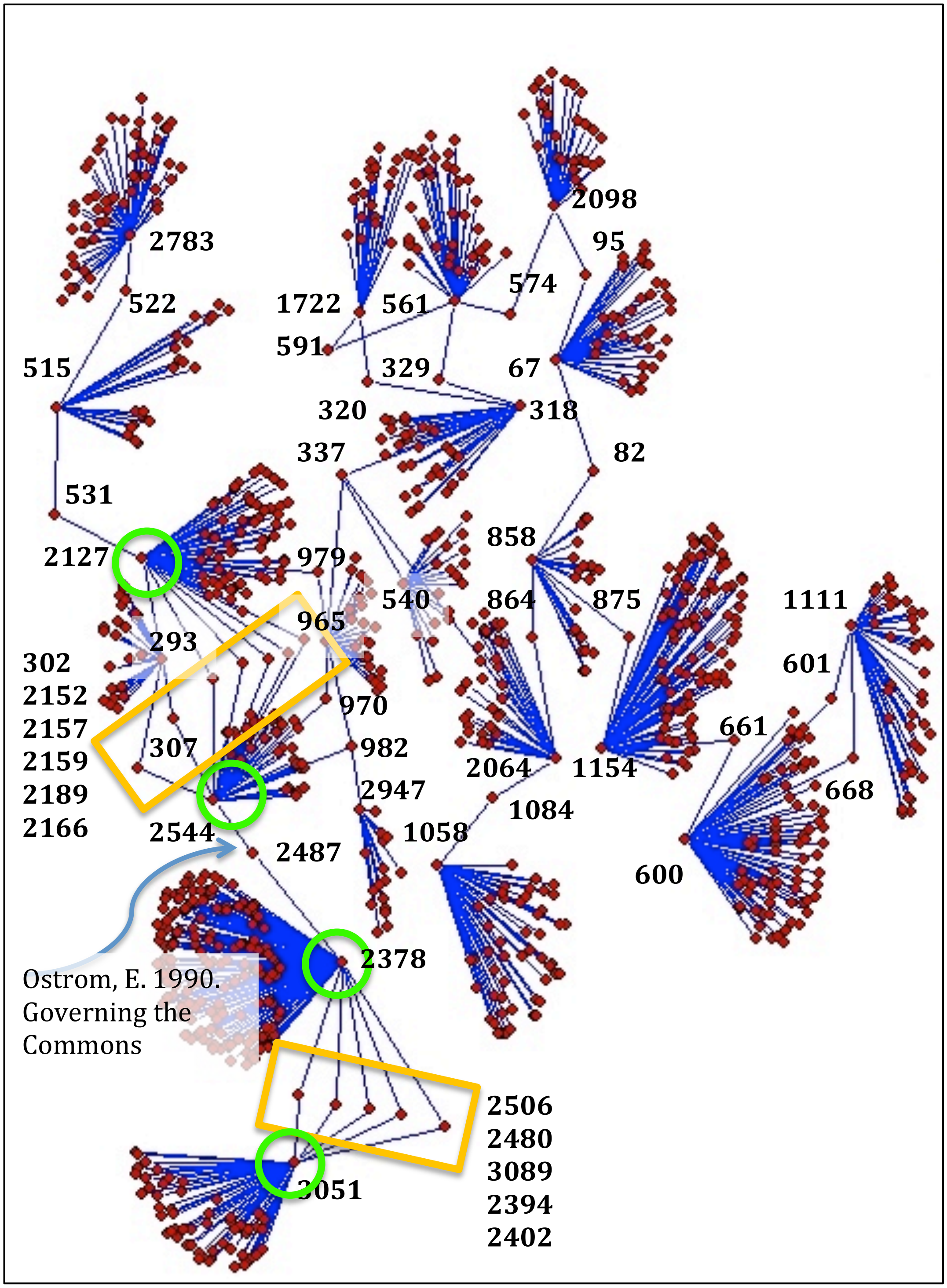


Figure 3.11. Frequency of Connections between Nodes with the Primary Network

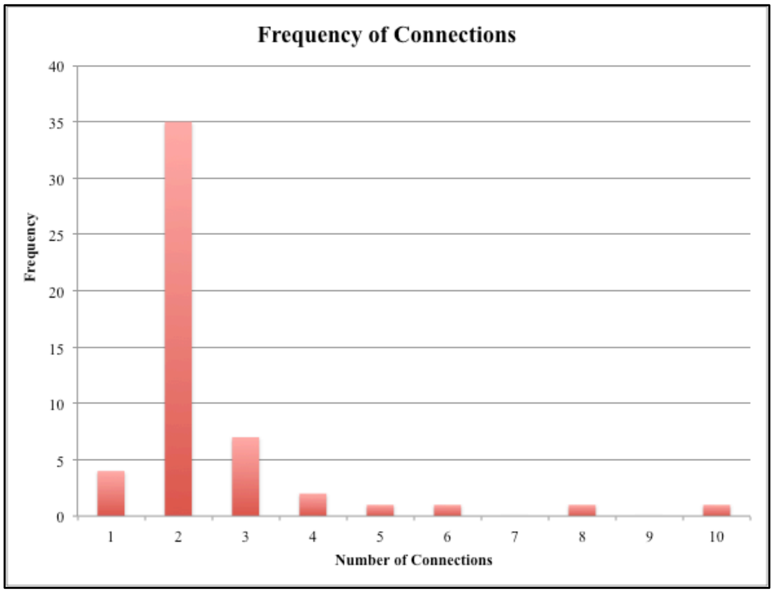
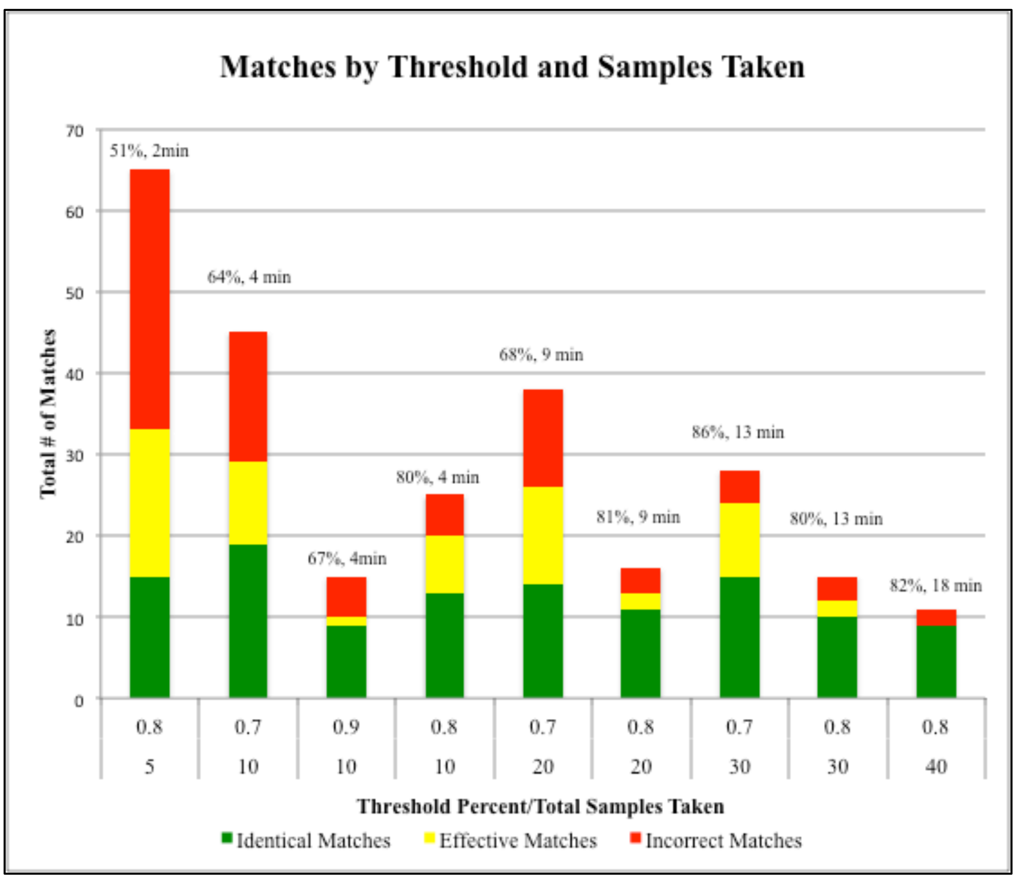


Figure 4.1. Match Integrity for a Sample of 1,250 Non-Journal Citations with Varied Numbers of Random Samples and Minimum Match Consistency



APPENDIX C

SCOPUS SEARCH

ALL(sanitation OR wastewater OR “waste water” OR sewage OR excrement OR blackwater OR “night soil” OR feces OR faeces OR sewer OR urine) AND ALL(“user-centered design” OR “user centered design” OR “user-centred design” OR “user centred design” OR “participatory action research” OR “community-based participatory research” OR “community based participatory research” OR “appropriate technologies” OR “action research” OR participatory OR “multiple criteria decision analysis” OR “multiple criteria decision modeling” OR “household centred environmental sanitation” OR “household centered environmental sanitation” OR “community-led total sanitation” OR “community led total sanitation” OR “bottom-up innovation” OR “bottom up innovation” OR “stakeholder participation” OR “local knowledge” OR “public participation” OR “social learning” OR “traditional ecological knowledge” OR “traditional knowledge” OR “sustainable development”) AND (PUBYEAR > 1999) AND (PUBYEAR < 2014) AND ALL(“develop* countr*” OR “developing world” OR “third world” OR “less developed countr*” OR “less-developed countr*” OR “developing nation*” OR “less developed nation*” OR “less-developed nation*” OR poverty OR “economically disadvantaged” OR “low income” OR “low-income” OR “millennium development goals”) AND ALL(engineering OR engineer OR engineers or technology) AND NOT(hospital) AND (LIMIT-TO(DOCTYPE,”ar”) OR LIMIT-TO(DOCTYPE,”ip”) OR LIMIT-TO(DOCTYPE,”bk”))

APPENDIX D

MATLAB SCRIPT

What follows is the MATLAB script for the Synapse program as of April 17, 2014, 12:45 PM. This file is entitled PajekAll_minus_starburst.m.

```
CLEAR
%% INTRODUCTION
%SCOPUS OUTPUT STANDARDIZER
%THIS CODE TAKES AN ASCII OUTPUT FROM SCOPUS AND EDITS IT SO THAT EACH
%ARTICLE OR REFERENCE CAN BE GIVEN A UNIQUE IDENTIFIER
%
%THE ASCII FILE MUST FIRST BE READ INTO MATLAB BY USING “UIIMPORT” AND
%IMPORTING THE TABLE.

SCOPUS = IMPORTDATA('SCOPUS_040214.TXT',"); %NOTE: BRIAN CHANGED THIS SO THERE IS NO
DELIMITER
SCOPUS = SCOPUS(1:4000,:);
%% CONSTANTS
COMMASPACE=(', ');
SPACE=(' ');
ALLARTICLES=[];
OUTPUT=[];

TIC; % TIMER FOR MAKING ALLARTICLES
%% CONCATENATION OF CELLS FOR ARTICLES AND GETTING RID OF THE WORD “REFERENCES: “
IN CELLS
X=FIND(STRNCMP('REFERENCES: ',SCOPUS,12));
FOR I = 1:LENGTH(X)
   A=X(I)-4; %GETS AUTHORS
   B=X(I)-3; %GETS ARTICLE TITLE
   C=X(I)-2; %GETS OTHER INFO (E.G., PUBYEAR, JOURNAL, ETC.)
   D=[SCOPUS(A) COMMASPACE SCOPUS(B) SPACE SCOPUS(C)];
   D=STRCAT(D(1),D(2),D(3),D(4),D(5)); %COMBINES STRINGS INTO ONE CELL
   ARTICLES(I,1)=D; %KEEPS TRACK OF ARTICLE STRINGS
   UNIQUE1={'A' NUM2STR(I) '-'}; %GENERATES A UNIQUE IDENTIFIER FOR EACH ARTICLE
   ARTICLES(I,2)=STRCAT(UNIQUE1(1),UNIQUE1(2),UNIQUE1(3)); %GIVES THE UNIQUE IDENTIFIER
TO EACH ARTICLE IN 'ARTICLES' ARRAY
   E=X(I);
   F=SCOPUS(E); %THIS CELL WILL ALWAYS BEGIN WITH “REFERENCES: “
   NEWREFS(I,1)=STRREP(F,'REFERENCES: ',"); %REMOVES “REFERENCES: “ FROM THIS CELL
   UNIQUE2={'A' NUM2STR(I) '-R1'};
   NEWREFS(I,2)=STRCAT(UNIQUE2(1),UNIQUE2(2),UNIQUE2(3));
END

%% CREATION OF OUTPUT MATRIX
FOR I = 1:LENGTH(X)
   G=ARTICLES(I,1:2); %GETS ARTICLE
   H=NEWREFS(I,1:2); %GETS FIRST REFERENCE OF ARTICLE
   IF I==LENGTH(X) %THIS IF STATEMENT GETS THE REST OF THE REFERENCES FOR THE ARTICLE
      J=[SCOPUS(X(I)+1:END)];
```

```
      K(2)={NUM2STR(I)};
      FOR O = 1:LENGTH(J)
        K(1)={'A'};
        K(3)={'-R'};
        K(4)={NUM2STR(O+1)};
        J(O,2)=STRCAT(K(1),K(2),K(3),K(4));
      END
    ELSE
      J=[SCOPUS(X(I)+1:X(I+1)-6)];
      K(2)={NUM2STR(I)};
      FOR O = 1:LENGTH(J)
        K(1)={'A'};
        K(3)={'-R'};
        K(4)={NUM2STR(O+1)};
        J(O,2)=STRCAT(K(1),K(2),K(3),K(4));
      END
    END
    K=VERTCAT(G,H,J); %VERTICALLY CONCATENATES ARTICLE AND CITATIONS
    ALLARTICLES=VERTCAT(ALLARTICLES,K); %FINAL OUTPUT OF ARTICLES WITH CITATIONS
END
FOR O = 1:LENGTH(ALLARTICLES)
    ALLARTICLES(O,3)={NUM2STR(O)};
END

TOC; % TIMER FOR MAKING ALLARTICLES

%% UNIQUE ID
% THIS PORTION OF THIS SCRIPT TAKES ALLARTICLES AND CHECKS FOR ANY MATCHES AND
REASSIGNES
% THE ID NUMBER SUCH THAT THE HIGHER NUMBERED ID RECEIVES THE LOWER
% NUMBERED ID.

% INPUTS
% ALLARTICLES :: [CHAR CHAR CHAR]. 'CITATION' 'A#-R#' 'ID'. (SEE ABOVE.)

% OUTPUTS
% OUTPUTUNIQUE :: [CHAR CHAR CHAR] 'CITATION' 'A#-R#' 'UNIQUE ID'

TIC; % TIMER FOR JOURNALS
OUTPUT=ALLARTICLES;

%%%%% BEGIN UNIQUE ID FOR JOURNALS.

JNJ = STRFIND(OUTPUT(:,1),' PP.'); % JOURNAL, NOT JOURNAL. EACH ENTRY I OF JNJ IS EMPTY IF '
PP.' WAS NOT FOUND IN CITATION I, AND IS THE INDEX AT WHICH ' PP.' IS FOUND IN CITATION I.
JNJP = STRFIND(OUTPUT(:,1),' P.'); %

%%%%% BEGIN UNIQUE ID FOR JOURNALS.


JNJ = STRFIND(OUTPUT(:,1),' PP.'); % JOURNAL, NOT JOURNAL. EACH ENTRY I OF JNJ IS EMPTY IF '
PP.' WAS NOT FOUND IN CITATION I, AND IS THE INDEX AT WHICH ' PP.' IS FOUND IN CITATION I.
JNJP = STRFIND(OUTPUT(:,1),' P.'); %

%BEGIN: DELETE ENTRIES WITH TWO CITATIONS MISTAKENLY STUCK TOGETHER IN THE FILE
FROM SCOPUS
```

```
SAVEPLACE = [];
FOR J=1:LENGTH(JNJ)
  IF SIZE(JNJ{J},2)>1 || SIZE(JNJP{J},2) > 1 % IF THE ENTRY HAS TWO OR MORE 'PP. ' LOCATIONS OR
TWO OR MORE 'P. ' LOCATIONS
      SAVEPLACE = [SAVEPLACE J]; % SAVE THE LOCATION OF THE BAD ENTRY.
  ELSEIF SIZE(JNJ{J},2)==1 && SIZE(JNJP{J},2)==1 % IF THE ENTRY HAS ONE 'PP. ' AND ONE 'P. '
      SAVEPLACE = [SAVEPLACE J];
  END
END

FOR PL = 1:LENGTH(SAVEPLACE)
   IF SAVEPLACE(PL)~= 1 && SAVEPLACE(PL) < SIZE(OUTPUT,1)
   OUTPUT = [OUTPUT(1:SAVEPLACE(PL)-1-(PL-1),:);OUTPUT(SAVEPLACE(PL)+1-(PL-
1):LENGTH(OUTPUT),:)];
   JNJ = [JNJ(1:SAVEPLACE(PL)-1-(PL-1),:);JNJ(SAVEPLACE(PL)+1-(PL-1):LENGTH(JNJ),:)];
   JNJP = [JNJP(1:SAVEPLACE(PL)-1-(PL-1),:);JNJP(SAVEPLACE(PL)+1-(PL-1):LENGTH(JNJP),:)];
   ELSE
   OUTPUT = OUTPUT(2:LENGTH(OUTPUT),:);
   JNJ = JNJ(2:LENGTH(JNJ),:);
   JNJP = JNJP(2:LENGTH(JNJP),:);
   END
END
 %END: DELETE ENTRIES WITH TWO CITATIONS MISTAKENLY STUCK TOGETHER IN THE FILE
FROM SCOPUS
 %SAVEPLACE IS A RECORD OF THE ROWS IN ALLARTICLES THAT HAVE BEEN DELETED TO
FORM OUTPUT.

NCITS = SIZE(OUTPUT,1);          % NUMBER OF CITATIONS IN LIST (INCLUDING ARTICLES AND
REFERENCES)

FOR J=1:NCITS
   OUTPUT{J,3} = NUM2STR(J);
END

JBIN = CELL(NCITS,3);            %INITIALIZING JOURNAL BIN
JPGSTART = CELL(NCITS);
JBINID = ZEROS(NCITS,1);
NJBIN = CELL(NCITS,3);           %INITIALIZING NON-JOURNAL BIN
NJBINID = ZEROS(NCITS,1);
COUNTJ = 0;
COUNTNJ = 0;

FOR J = 1:NCITS
   IF ISEMPTY(JNJ{J}) && ISEMPTY(JNJP{J})       % IF NEITHER ' PP.' NOR ' P.' WAS FOUND
      COUNTNJ = COUNTNJ+1;
      NJBIN(COUNTNJ,:) = OUTPUT(J,:);          % PLACE IT IN A NON-JOURNAL BIN.
   ELSEIF ~ISEMPTY(JNJP{J}) && ISEMPTY(JNJ{J})   % IF ' P.' IS FOUND BUT NOT ' PP.'
      COUNTJ = COUNTJ+1;
      JBIN(COUNTJ,:) = OUTPUT(J,:);           % PLACE IT IN A JOURNAL BIN.
      JPGSTART{J} = JNJP{J} + 4;               % SAVE THE START LOCATION OF PAGE NUMBER TO
THE JPGS LIST
   ELSEIF ~ISEMPTY(JNJ{J}) && ISEMPTY(JNJP{J})   % IF ' PP.' WAS FOUND, BUT NOT ' P.'
      COUNTJ = COUNTJ+1;
      JBIN(COUNTJ,:) = OUTPUT(J,:);           % PLACE IT IN A JOURNAL BIN.
      JPGSTART{J} = JNJ{J} + 5;               % SAVE THE START LOCATION OF PAGE NUMBER TO THE
JPGS LIST
```

```
   ELSE
      FPRINTF('BOTH " PP." AND " P." WERE FOUND IN CITATION %.0F \N',J)
   END
END

%SPLICE OFF BLANK ENTRIES.
JBIN = JBIN(1:COUNTJ,:);
JBINID = JBINID(1:COUNTJ,:);
NJBIN = NJBIN(1:COUNTNJ,:);
NJBINID = NJBINID(1:COUNTNJ,:);

%CHECK THAT ALL CITATIONS WERE SORTED.
IF LENGTH(JBIN)+LENGTH(NJBIN) ~= NCITS
FPRINTF('ERROR: CITATION LOST OUTSIDE OF JBIN AND NJBIN.\N')
END


JCITCHAR = CHAR(JBIN(:,1));     % TURN CITATIONS INTO CHARACTER ARRAYS.
JPGS = CELL(COUNTJ,1);          % INITIALIZING
LOCPG = CELL2MAT(JPGSTART);         % CONVERT TO DOUBLE AND REMOVE EMPTY ENTRIES.

FOR NN = 1:COUNTJ
   TICK = 1;
   WHILE LOCPG(NN)+TICK <= SIZE(JCITCHAR,2) && JCITCHAR(NN,LOCPG(NN)+TICK) ~= '.' &&
JCITCHAR(NN,LOCPG(NN)+TICK)~= ';' && JCITCHAR(NN,LOCPG(NN)+TICK) ~= ' '
    JPGS{NN} = JCITCHAR(NN,LOCPG(NN):LOCPG(NN)+TICK);
    TICK = TICK+1;
   END
END

RELABELED = ZEROS(COUNTJ,1); % INITIALIZING
R = 1;
FOR M = 1:COUNTJ
   MATCHPG = STRCMPI(JPGS{M},JPGS);
   PGMATCHES = FIND(MATCHPG);
   NM = LENGTH(PGMATCHES)-1;
   IF NM > 0
      CITMATCHES = JCITCHAR(PGMATCHES,:);          % EXTRACT MATCHING CITATIONS
      FIRSTAUTHOR = CELL(NM+1,1);                  % INITIALIZING
      FOR K = 1:NM+1;
      BLAST = STRSPLIT(CITMATCHES(K,:),' ');
      FIRSTAUTHOR(K) = BLAST(1);
      END
      AUMATCH = STRCMPI(FIRSTAUTHOR{1},FIRSTAUTHOR);  % ARRAY OF LENGTH NM+1. 1 IF
MATCHING FIRST CITATION. 0 OTHERWISE.
      PG = PGMATCHES.*AUMATCH;
      IF LENGTH(FIND(PG))-1 ==0;
         %FPRINTF('NOT A REAL MATCH BASED ON FIRST WORD IN CITATION.\N')
      ELSE   %ADD IN HERE A WAY TO AVOID RELABELING OF E.G., 13(FORMERLY 83) TO 13 FOR
FASTER COMPUTATION.
         WHERE = FIND(PG);
         RELABELED(R:R+LENGTH(WHERE)-1) = STR2DOUBLE(JBIN([PG(WHERE)],3));
         OUTPUT([RELABELED(R:R+LENGTH(WHERE)-1)],3) = JBIN(PG(1),3); %RELABEL
         JBIN([PG(WHERE)],3) = JBIN(PG(1),3);
         R = R+LENGTH(WHERE)-1;                            % COUNT THE NUMBER OF LABELS
RELABELED.
```

```
      END
    END
END
TOC; % TIMER FOR JOURNAL

TIC; % TIMER FOR NON-JOURNAL
%%%%% BEGIN UNIQUE ID FOR NON-JOURNAL

N = 20;                          % NUMBER OF RANDOM SAMPLES FROM CITATION TO MATCH BY
L = 20;                         % LENGTH OF RANDOM SAMPLE TO EXTRACT FROM A CITATION
THRESHOLD = 14;                   % NUMBER OF RANDOM SAMPLES OUT OF N WHICH MUST BE
MATCHING TO BE CATEGORIZED AS A MATCH
%NEW
TOTALNUMBEROFMATCHES = 0;
IDSMATCHED = ZEROS(2,COUNTNJ);
%NEW
FOR C = 1:COUNTNJ                % FOR EACH CITATION IN THE NJ BIN
    MATCHCOUNT = ZEROS(COUNTNJ,1);  % INITIALIZING
    CIT = NJBIN{C,1};             % GET CITATION STRING
IF LENGTH(CIT) < L
    FPRINTF('CITATION LENGTH IS SHORTER THAN %.0F CHARACTER SAMPLE LENGTH\N',L)
ELSEIF ISEMPTY(FIND(IDSMATCHED==STR2DOUBLE(NJBIN(C,3)))) % IF THIS CITATION HAS NOT
ALREADY BEEN MATCHED
    MAX = LENGTH(CIT)-L;          % SET MAXIMUM OF RANDOM STRING GRAB LOCATION
  FOR N = 1:N                    % FOR EACH RANDOM SAMPLING
    GRAB = FLOOR(RAND*MAX) + 1;     % UNIFORM DISTRIBUTION RANDOM LOCATION FROM
WHERE SAMPLE BEGINS. PLUS 1 AVOIDS A “0” START LOCATION.
    RS = CIT(GRAB:GRAB+L-1);       % RANDOM SAMPLE OF 20 LENGTH FROM CITATION
    F = STRFIND(NJBIN(:,1),RS);
    % ASSUME ONLY ONE MATCH WILL BE FOUND WITHIN A GIVEN CITATION.
    K = NUM2CELL(ZEROS(COUNTNJ,1));
    FOR M = 1:COUNTNJ             % FOR EACH POTENTIAL MATCH
      IF LENGTH(CELL2MAT(F(M)))~=0 && M~=C % IF MATCH HAS BEEN FOUND IN MTH CITATION
AND IS NOT A SELF-MATCH
      K{M} = F{M};
      MATCHCOUNT(M) = MATCHCOUNT(M)+1;
      END
    END
  END
  F = FIND(MATCHCOUNT);           % FIND LOCATION IN NJBIN OF CITATIONS WHICH HAD
MATCHES TO CITATION “C”
  M = MATCHCOUNT(F) >= THRESHOLD;   % M(I)=0 FOR NON MATCH, 1 FOR MATCH, BASED ON
“THRESHOLD”
  MATCHES = NONZEROS(F.*M);        % ID IN NJ BIN CORRESPONDING TO MATCHES FOR CITATION
“C”
  IF ~ISEMPTY(MATCHES)            % IF MATCHES ARE FOUND,
  OID = NJBIN([MATCHES],3);        % GET ORIGINAL ID
  OID = STR2DOUBLE(OID);           % GET ORIGINAL ID IN NUMBER FORM
  OUTPUT([OID],3) = NJBIN(C,3);     % RELABEL
  NJBIN([MATCHES],3) = NJBIN(C,3);
  %NEW
  IDSMATCHED(1,TOTALNUMBEROFMATCHES+1:TOTALNUMBEROFMATCHES+SUM(M))= OID;
  IDSMATCHED(2,TOTALNUMBEROFMATCHES+1:TOTALNUMBEROFMATCHES+SUM(M))=
STR2DOUBLE(NJBIN(C,3));
  TOTALNUMBEROFMATCHES = TOTALNUMBEROFMATCHES+SUM(M);
  %NEW
```

```
  END
END
END

OUTPUTUNIQUE = OUTPUT; % RENAME FINAL PRODUCT FOR NOMENCLATURE CLARITY.
TOC; % TIMER FOR NON-JOURNALS


%% INSERT THE LABEL PORTION OF SCRIPT HERE

TIC; % TIMER FOR MAKING PAJEK FILE
%% PAJEK FILE
OUTPUT={'*VERTICES'};
EDGES = CELL(1,1);
N=(OUTPUTUNIQUE(:,2));%GRABS COLUMN 2 OF OUTPUTUNIQUE
P=(OUTPUTUNIQUE(:,3));%GRABS COLUMN 3 OF OUTPUTUNIQUE
V=STR2DOUBLE(P(:,1));
CLEAR MAX
W=MAX(V);
IF LENGTH(P)<W
   N(LENGTH(N):W)={NUM2STR(ZEROS)};
   P(LENGTH(P):W)={NUM2STR(ZEROS)};
END
FOR I = 1:LENGTH(P)
   R=FIND(STRNCMP(NUM2STR(I),P,10)); %FINDS INSTANCES OF MATCHED NUMBERS AND
CONSOLIDATES THEM SO IT ONLY SHOWS UP ONCE IN PAJEK.
   IF LENGTH(R)>=1
      OUTPUT(LENGTH(OUTPUT)+1,1)={P{I}};
      %OUTPUT(LENGTH(OUTPUT),2)={'"LABEL"'};
      LABELQUOTE={'"' N{I} '"'};
      OUTPUT(LENGTH(OUTPUT),2)=STRCAT(LABELQUOTE(1),LABELQUOTE(2),LABELQUOTE(3));
%WE'LL NEED TO FIGURE OUT HOW TO GET THE LABELS TO WORK
   END
   R=[];
END
FOR I=2:LENGTH(OUTPUT)
   NEWMATCH(I-1,1)=OUTPUT(I,1);
   OUTPUT(I,1)={NUM2STR(I-1)}; %FIXES NUMBERS IN OUTPUT SO THEY ARE SEQUENTIAL
   NEWMATCH(I-1,2)=OUTPUT(I,1);
   PAJEK_REFS(I-1,1)=NEWMATCH(I-1,2);
   PAJEK_REFS(I-1,2)=OUTPUTUNIQUE(STR2DOUBLE(NEWMATCH(I-1,1)),1);
END
OUTPUT(1,2)={NUM2STR(LENGTH(OUTPUT)-1)};
OUTPUT{LENGTH(OUTPUT)+1,1}=('*EDGES');
OUTPUT(:,3)={''};
FOR I = 1:LENGTH(ARTICLES)
   OH=0;
   L(1)={'A'};
   L(2)={NUM2STR(I)};
   L(3)={'-'};
   M=STRCAT(L(1),L(2),L(3));
   Y=FIND(STRNCMP(N,M,3)); %FINDS INSTANCES OF "A#-" AND STORES THE CORRESPONDING
ROW
   FOR O=2:LENGTH(Y)
      IF LENGTH(EDGES)==1
         EDGES(1,1)=P(Y(1)); %TAKES ROW # FROM 'Y', GETS VALUE FROM CORRESPONDING ROW IN
```

```
'P' AND PUTS THE VALUE IN OUTPUT.
         EDGES(1,2)=P(Y(O));
         EDGES(1,3)={NUM2STR(1)};
      ELSEIF LENGTH(EDGES)==3 && OH==1
         EDGES(2,1)=P(Y(1)); %TAKES ROW # FROM 'Y', GETS VALUE FROM CORRESPONDING ROW IN
'P' AND PUTS THE VALUE IN OUTPUT.
         EDGES(2,2)=P(Y(O));
         EDGES(2,3)={NUM2STR(1)};
      ELSEIF LENGTH(EDGES)==3 && OH==2
         EDGES(3,1)=P(Y(1)); %TAKES ROW # FROM 'Y', GETS VALUE FROM CORRESPONDING ROW IN
'P' AND PUTS THE VALUE IN OUTPUT.
         EDGES(3,2)=P(Y(O));
         EDGES(3,3)={NUM2STR(1)};
      ELSE
         EDGES(LENGTH(EDGES)+1,1)=P(Y(1)); %TAKES ROW # FROM 'Y', GETS VALUE FROM
CORRESPONDING ROW IN 'P' AND PUTS THE VALUE IN OUTPUT.
         EDGES(LENGTH(EDGES),2)=P(Y(O));
         EDGES(LENGTH(EDGES),3)={NUM2STR(1)};
      END
      OH=OH+1;
   END
END
FOR I = 1:2
   FOR O = 1:LENGTH(EDGES)
      FOR U = 1:LENGTH(NEWMATCH)
         IF STRCMP(EDGES(O,I),NEWMATCH(U,1))==1
            EDGES(O,I)=NEWMATCH(U,2);
         END
      END
   END
END

OUTPUT = VERTCAT(OUTPUT,EDGES);

OUTPUT=OUTPUT';
FID = FOPEN('PAJEK.NET', 'W');
FPRINTF(FID, '%S     %S     %S\N', OUTPUT{:});
FCLOSE(FID);

PAJEK_REFS=PAJEK_REFS';
FID = FOPEN('PAJEK_REFERENCES.TXT', 'W');
FPRINTF(FID, '%S     %S\N', PAJEK_REFS{:});
FCLOSE(FID);

TOC; % TIMER FOR MAKING PAJEK FILE.
```